Volume 29 SEPTEMBER, 1945 Number 9

BULLETIN
of the
American Association *of* Petroleum Geologists

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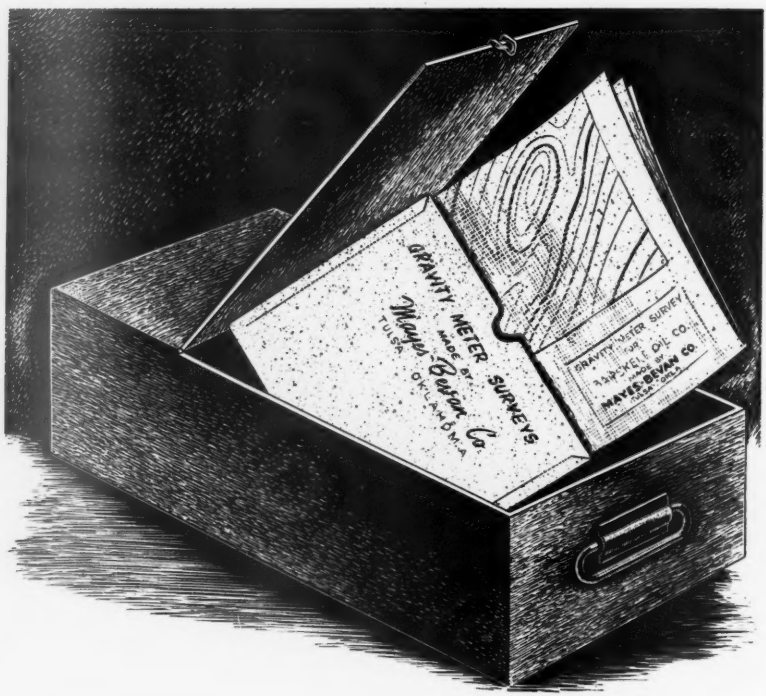

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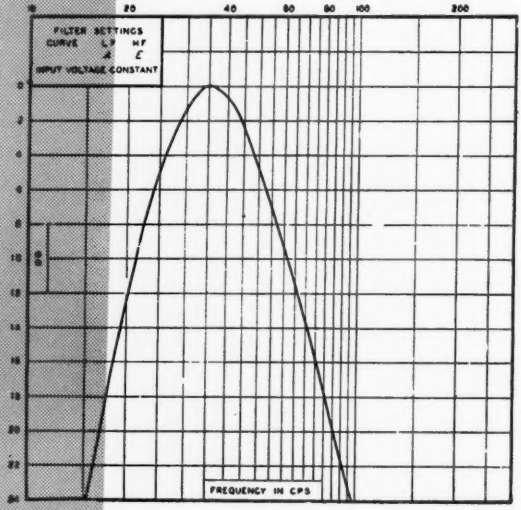

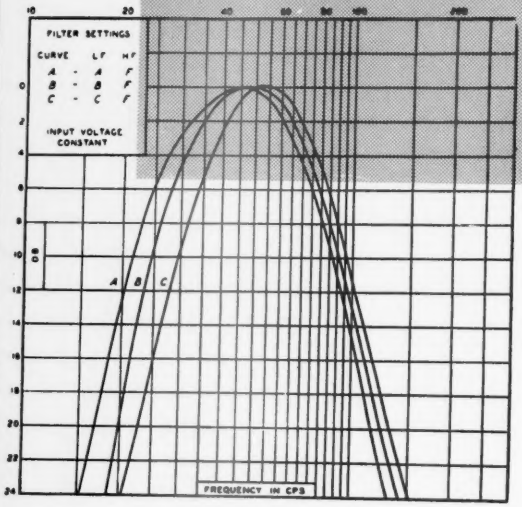

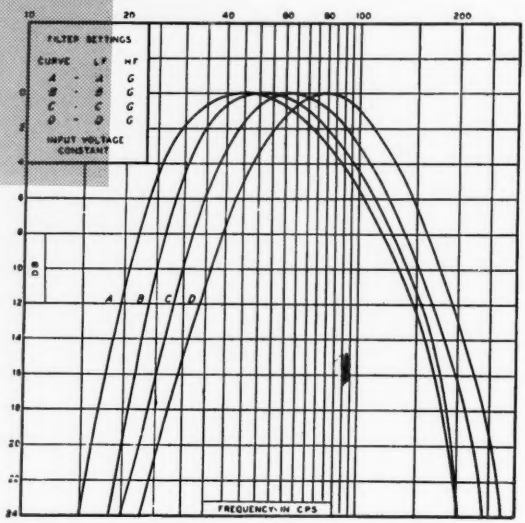

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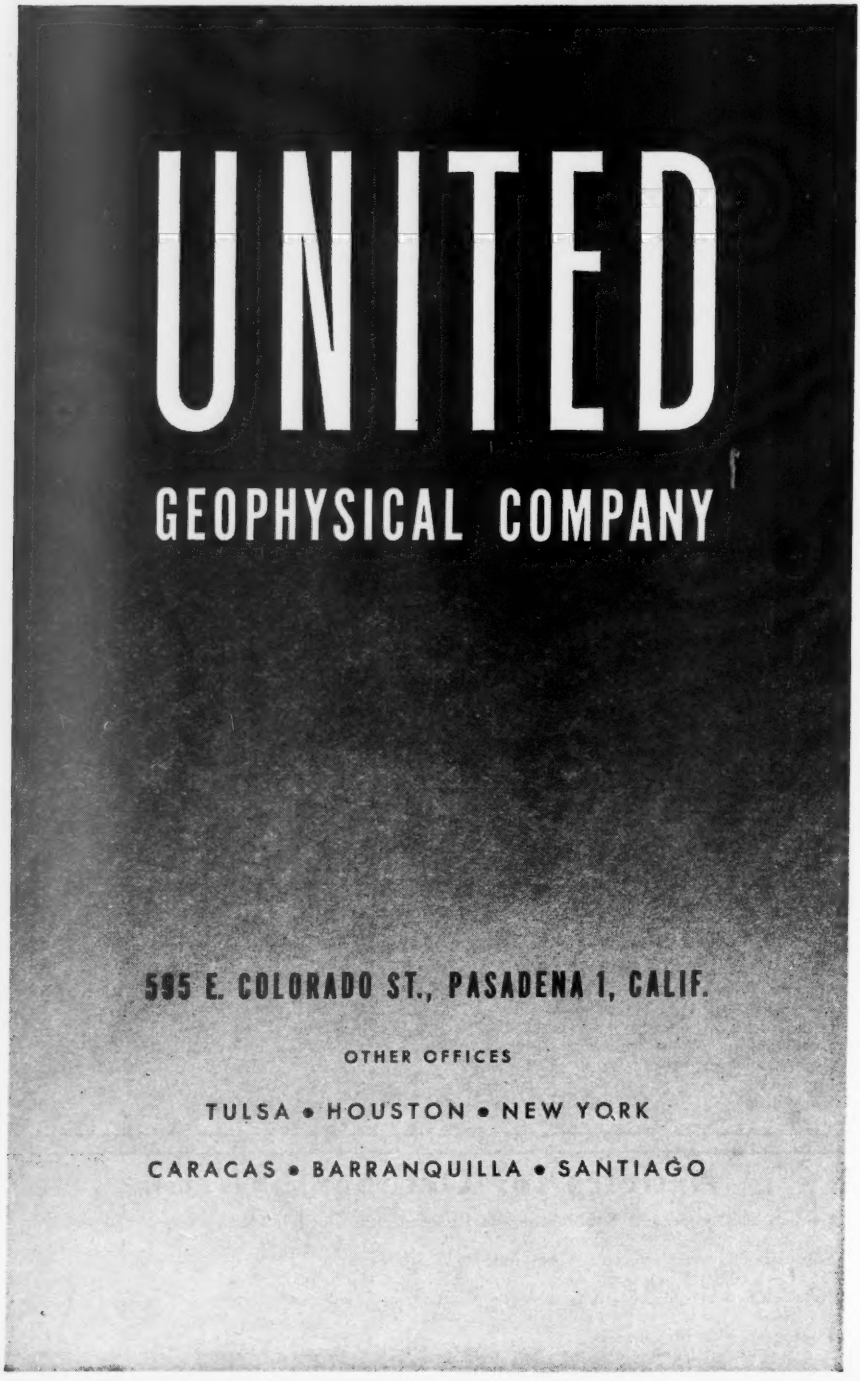
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Volume 29 Number 9

BULLETIN
of the
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SEPTEMBER, 1945

RECENT SEDIMENTATION AND THE SEARCH FOR PETROLEUM[1]

W. C. KRUMBEIN[2]
Pittsburgh, Pennsylvania

ABSTRACT

The thesis of this paper is that sedimentary characteristics will become increasingly important in the search for oil. Emphasis is placed on the increase in quantification of sedimentary data; new and more complete studies of sedimentary environments; application of the techniques to ancient sediments; and the development and improvement of methods for recording the quantitative data in map form. A brief review is given of some trends in modern sedimentation, illustrated by particle roundness and sphericity, as an introduction to quantitative sedimentary studies. The viewpoint is extended to environments of sedimentation, approached as "closed systems" with boundary conditions, materials, and energy sources as the basic subjects of study. The data of quantitative environmental studies lend themselves to presentation on contour-type maps and surfaces, and some of the geometrical properties of such maps and surfaces are reviewed. A classification of maps is given, to indicate the wide range of sedimentary data both recent and ancient, suitable for presentation in this manner.

INTRODUCTION

The increased importance of stratigraphic traps to future oil reserves focusses attention on methods of exploration applicable to such traps. Sedimentary characteristics in part control the localization of stratigraphic traps, and principles of sedimentation are playing an increasing role in exploration. Present methods, typified by isopach and regional stratigraphic studies, supported by sedimentary and stratigraphic principles, indicate the more promising counties or townships for exploration, but the problem is to narrow down the scale to the particular section. The methods of quantitative sedimentation afford one means of narrowing the attack by furnishing more complete pictures of sedimentary processes and characteristics.

Within the past two decades advances in some fields of sedimentation have been very rapid. Techniques for the quantitative measurement of sedimentary attributes have been developed; the geological significance of particle properties

[1] This paper was presented under the auspices of the Distinguished Lecture Committee of the American Association of Petroleum Geologists during February-March, 1945. Manuscript received, May 31, 1945.

[2] Gulf Research and Development Company. At the time this paper was written, the author was senior geologist, Beach Erosion Board, War Department, Washington, D. C.

is better understood; lateral variations within sedimentary environments are being studied; and a body of theoretical knowledge is being made available for application to practical geological problems. There is, however, a gap between theoretical studies and their practical application, partly because many sedimentary papers are concerned with specific problems of technique or analysis, and it is difficult to obtain an over-all view of the subject from them. To the extent that these specific advances can be related to trends in the science, however, gaps between theory and practice can be more successfully bridged.

Several writers, among them Knopf (1),[3] Twenhofel (2), Trask (3), Pettijohn (4), and Levorsen *et al.* (5) have discussed the past and future of sedimentation, and the consensus is that quantification of data is an increasing trend in sedimentary studies. The present paper offers a case for quantitative sedimentary petrology and indicates some of its possible uses in applied fields of geology. The main theme of the paper is presented in two parts. In the first the quantitative approach is illustrated by the study of particle properties, using roundness and sphericity as examples. The approach is extended to environments of sedimentation to illustrate future applications of the method. In the second part are discussed methods of presenting the numerical data on maps, to illustrate how advances in the theoretical phases of the science are and may be converted to forms directly usable in applied geology.

1. QUANTITATIVE APPROACH TO SEDIMENTARY PROBLEMS

As an illustration of the manner in which the quantitative study of sediments progresses, the development of a specific line of inquiry may be sketched. Merely for convenience the writer uses some of his own data, with no implication that they are more than illustrative. The treatment is purposely kept rather generalized, to emphasize the point of view rather than the specific examples. Among clastic sediments the properties of the individual particles are fundamental in determining their behavior, and hence in interpreting the past history of the sedimentary deposits. The interpretive aspects of sedimentation follow the descriptive, and in any sedimentary study certain basic descriptive data are needed. These include (a) the areal extent and thickness of the formation, (b) its geological age, (c) its relation to other formations, (d) its textural and other variations vertically and laterally, and (e) the history of its structural deformations. This information is obtained by standard methods of field mapping, paleontology, stratigraphy, subsurface correlation, and the like. With these data at hand, the more interpretive or inferential questions are considered. These include (f) the parent material and source area of the sediment; (g) the agent of transportation, and (h) the environmental conditions at the site of deposition.

Application to particle properties.—It is with respect to the last three questions that quantitative sedimentation may play its greatest role, and here the properties

[3] See numbered references in bibliography at end of paper.

of the particles enter directly into the problem of reading sedimentary history. (For simplicity, only clastic sediments are considered here.) Certain particle attributes, such as size, shape, and mineral composition, were early recognized to be of importance, and more recently other attributes have received attention. In developing a systematic quantitative approach to particle properties, one may list all the attributes which are measurable, and from them select those which are important in sedimentation. Among the large list of geometrical, optical, crystallographic, chemical, mechanical, thermal, electrical, and magnetic properties which all particles have (6), the geometrical, chemical, and mechanical are most important from a sedimentary point of view. Experience has shown that six particle properties are of basic importance:

1. Size (volume, sieve mesh, settling velocity, intercepts)
2. Shape (sphericity or equi-dimensionality)
3. Roundness (relation of corners and edges to particle as a whole)
4. Surface texture (pitting, polish, frosting, *et cetera*)
5. Mineral composition (includes density, hardness, *et cetera*)
6. Orientation (disposition of particle axes in space: fabric).

Of these six attributes, only surface texture has not been quantified. This is probably due in part to a composite of several variables in the concept, which must be first isolated and defined. A similar situation existed for many years with the general shape concept, and some confusion is still extant regarding the significance of sphericity and roundness. These two latter properties will be discussed here as examples of the development of quantitative thinking about particle properties.

Although Wentworth in 1922 (7) recognized the difference between flatness (shape) and roundness, it was Wadell in 1932 (8) who first showed systematically that two geometrically distinct variables are included in the general shape concept. These were defined as *sphericity* and *roundness*, and methods were presented for measuring them. The wide application of Wadell's concepts awaited less time-consuming methods of measurement, and at present studies of sphericity and roundness play a prominent part in many sedimentary studies. Details of the original and later methods are given in the bibliography (9–19), but for present purposes a simplified two-dimensional approach is presented to develop the ideas.

Figure 1 is a scattering of sand grains. To gain an impression of sphericity, the short and long intercepts through the particles may be compared, although in practice sphericity is usually measured as a three-dimensional concept. In particle *a*, the short axis is nearly as long as the long axis; the approach to equidimensionality is about 0.9. Particle *b*, on the other hand, has a short axis about half as long as the longer axis, and the equidimensionality or sphericity is about 0.5. The sphericity concept is independent of the size and angularity of the particles. For roundness one compares the diameters of the corners or edges with the diameter of the largest circle that can be inscribed in the particle image. In particle *c* the average diameter of the smaller circles is about 0.4 that of the inscribed circle; hence the roundness is 0.4. In particle *d* the ratio of the end circles to the central

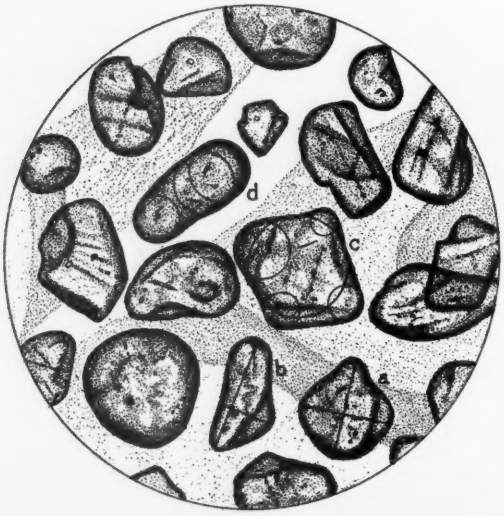

FIG. 1.—Sand grains, illustrating concepts of sphericity and roundness.

FIG. 2.—Exposure of flood gravel, Arroyo Seco, California. Cobble in left foreground is about 8 inches long.

circle is larger, so that the roundness is nearly 0.9. Particle *d*, incidentally, has a sphericity of only about 0.5. By comparing other particles in the figure it may be seen that various combinations of sphericity and roundness occur. The large particle in the lower left has both high sphericity and high roundness. Roundness as a concept is geometrically independent of particle size and sphericity.

Once quantitative definitions are set up, they may be applied to deposits in the field or to samples in the laboratory, and average sphericities and roundnesses

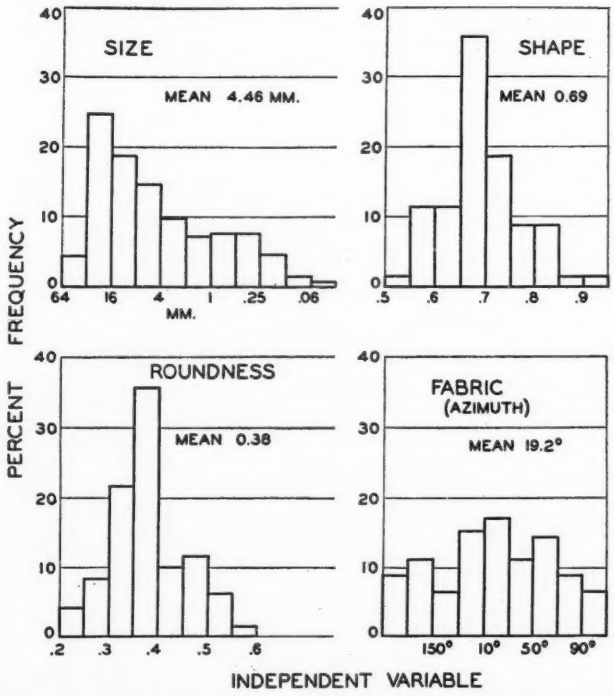

FIG. 3.—Histograms of size, sphericity, roundness, and fabric of gravel in Figure 2.

determined. Figure 2 shows an exposure of flood gravel. In the conventional field approach notes are made on the thickness of the deposit, the presence of the open-work seam, the prevailing sizes of pebbles present, the poorness of the sorting, and so on. Quantitatively some of these and other observations can be recorded graphically or numerically by analyzing a sample. Figure 3 shows several histograms which translate the visual picture of the outcrop into quantitative data. The upper left histogram shows the size distribution, and indicates a deposit with average size 4.5 mm., poorly sorted. The upper right and lower left histograms

illustrate the contrast between the shape (sphericity) and roundness. Whereas the average sphericity is 0.7, the average roundness is only 0.4. The average particle in the deposit may therefore be visualized as a pebble about 5 mm. long, having an oval image in which the shorter axis is about 0.7 as long as the long axis, and with corners or edges having a diameter 0.4 times that of the inscribed circle. The lower right histogram illustrates another aspect of the deposit. It shows that

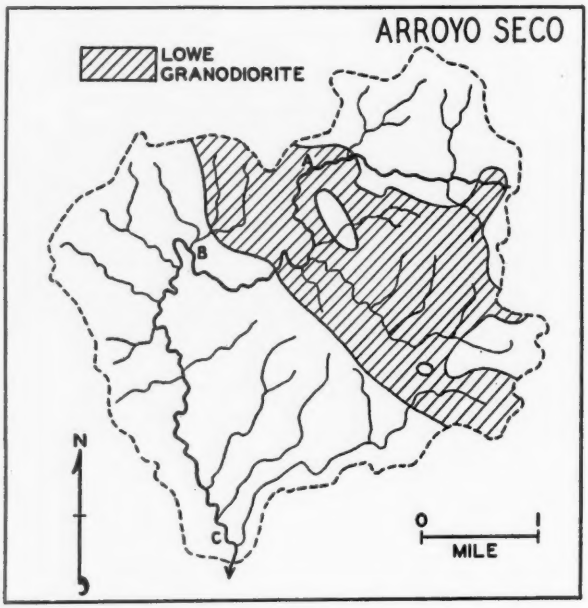

FIG. 4.—Sketch map of Arroyo Seco, Los Angeles County, California, showing area of Lowe granodiorite.

the long axes of the pebbles are oriented on the average about 20° east of north, which is the upstream direction. Thus a perceptible but not marked imbrication is present.

The significance of any outcrop increases as its relation to other parts of the deposit are studied. The gravel in Figure 2 occurs along Arroyo Seco (Fig. 4), located a short distance northwest of Pasadena, California, in the San Gabriel Mountains (20). Along its course the stream cuts an area of granodiorite, such that beyond tributary B in the figure no rocks of this type enter the main stream until point C is reached. Hence the progressive changes in granodiorite pebbles may be studied free of any contamination en route. Samples were collected at intervals along the stream from point A to point C, and Figure 5 shows the initial

and final samples of a restricted size of pebbles (16–32 mm.). Comparison of the two sets of pebbles shows that the initial sample has a low roundness (0.1), whereas the final sample is moderately rounded (0.4). With respect to the sphericity, however, there is little change. In both sets of pebbles the average short axis is about 0.7 as long as the longer axis. Thus the series of samples shows a fourfold increase in roundness but essentially no change in sphericity. This demonstrates not only that roundness and sphericity are geometrically distinct, but that they behave differently under the same dynamic circumstances. This

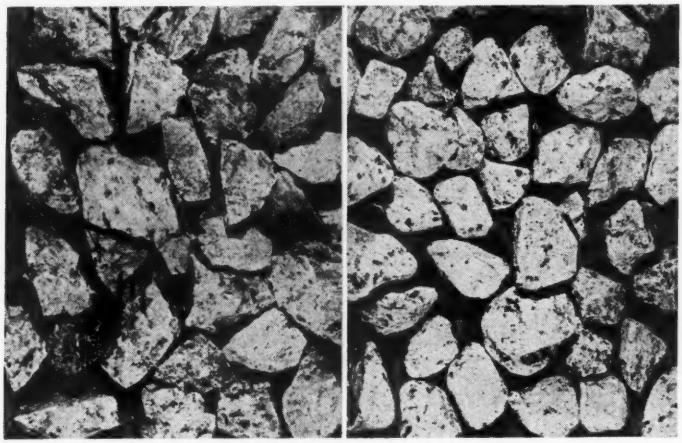

FIG. 5.—Granodiorite pebbles, Arroyo Seco. *Left*, from point A (Fig. 4); *right*, from point C.

contrast in behavior is brought out in Figure 6, which is a graph of the average values of all the samples. It shows a nearly horizontal line for the sphericity, and a rising curve for roundness. From an initial steeper portion the roundness curve flattens to a trend at about 0.4.

The problem raised by these relations is to account for a situation in which the roundness may change markedly without any important change in sphericity, as well as to examine why the roundness apparently approaches a limiting value. In part, the problem is one of abrasion, and experimental data on abrasion prove helpful. Figure 7 shows curves of size, sphericity, and roundness changes in rock particles during abrasion in a tumbling barrel (21). The striking feature is the rapidity of the initial change in roundness, with the marked flattening of the curve in later stages, in contrast to the slight sphericity change. The parallelism of the later portions of the roundness and sphericity curves is also apparent, and from mathematical analysis of the experimental data it is found that the limitation in rounding during later stages is partly controlled by the initial sphericity

and by the change in sphericity during the process. Thus it may be said (with some qualifications) that the rounding process is controlled by the sphericity, such that the greater the total sphericity change, the larger the value of the roundness at any point along the curve. Thus what began originally as two separate geometrical concepts is seen to be two distinct dynamic concepts, with sphericity more fundamental than roundness even during abrasion. From the nature of the rounding curve, which flattens appreciably after its initial rise, it is apparent

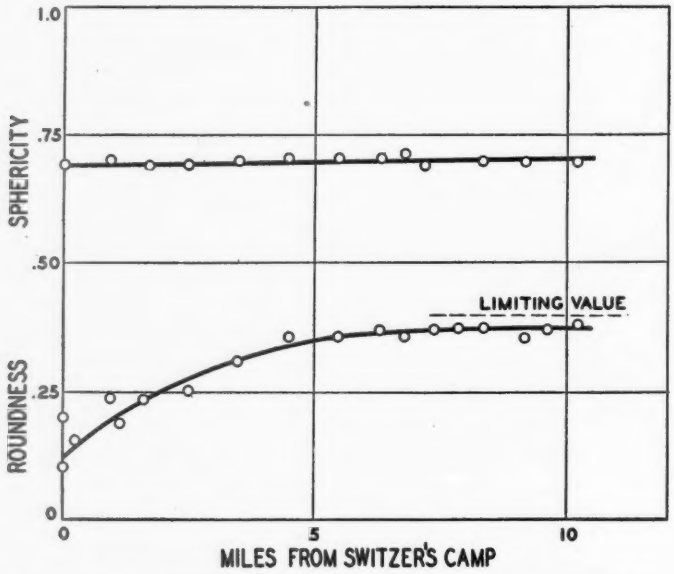

FIG. 6.—Sphericity and roundness of Lowe granodiorite pebbles from Arroyo Seco.

that the greatest significance in interpreting particle roundness will apply in the steep part of the curve, that is, near the source of the sediment.

This brief discussion illustrates how the conversion of sedimentary observations into numbers helps clarify the understanding of particle properties. Yet abrasion is only one aspect of particle behavior. The illustration given for Arroyo Seco is complicated by a second process which goes on in streams, the process of selective transportation. Particle size, shape, and density all influence particle transportation, so that selection during transport may proceed on the basis of all or any of these factors. In Arroyo Seco selective transportation was a factor, so that for a more complete understanding of sphericity and roundness, their relative behavior during transportation needs consideration.

The effects of sphericity and roundness on particle transportation can be studied to a first approximation in the laboratory, using particles of a given size

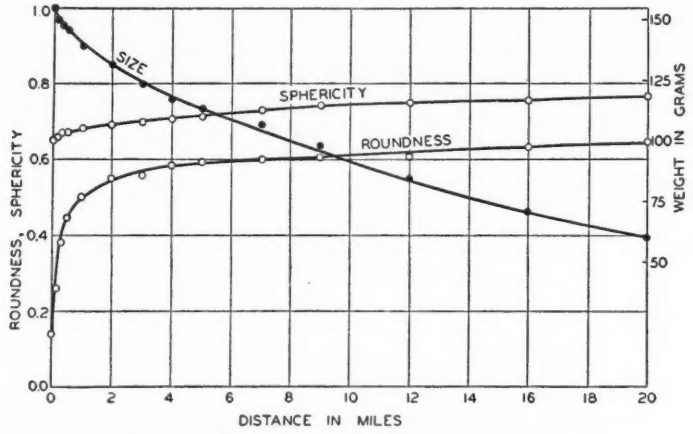

FIG. 7.—Abrasion curves of limestone fragments (21).

and density, but varying in sphericity and roundness. The writer attacked one aspect of the problem (22), using a sediment flume of the type shown in Figure 8. The equipment consisted of a wooden flume 22 feet long, about 6 inches wide, and about 1 foot deep. Water flows from a constant-head tank into a stilling basin

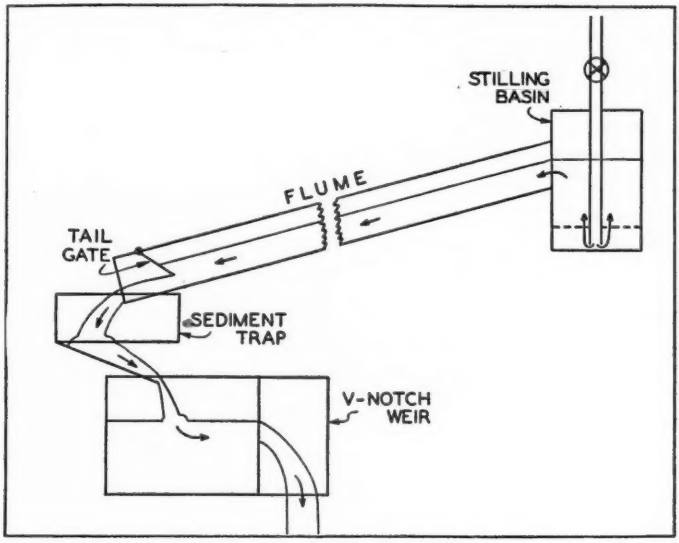

FIG. 8.—Sketch of sediment flume (not to scale).

which leads to the flume. The flow conditions are controlled by adjusting the slope, the tail-gate, and the discharge. The latter is measured by the weir over which the water flows after it leaves the flume and passes through a sediment basket to collect the particles. From the discharge and depth relations the average velocity of the water in the flume can be computed.

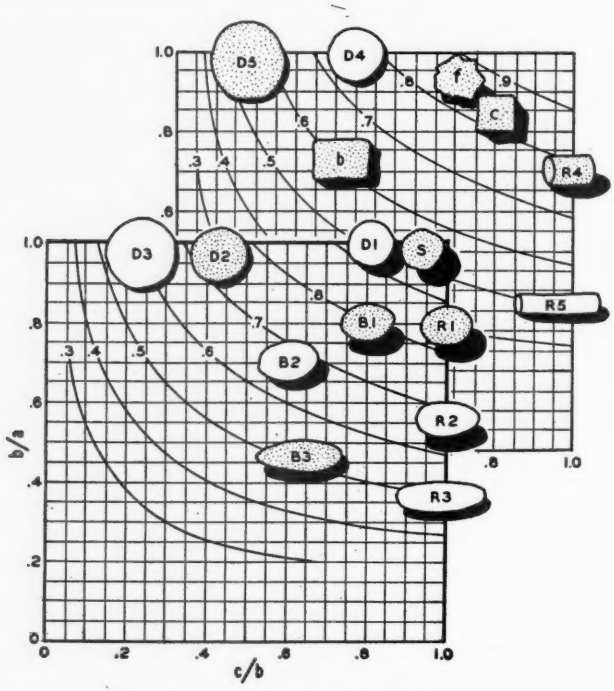

FIG. 9.—Particles used in flume experiment. Curved lines on graphs are lines of equal sphericity. (Stippled particles are used in Figure 10.)

The particles used in the experiment were prepared from cement mortar, and consisted of two sets of forms as shown in Figure 9. The first was a series of oblate spheroids (disks), prolate spheroids (rollers), and triaxial ellipsoids (blades), which progressively approached a sphere. The second set consisted of various arbitrary forms including a cube, several coin-like disks, and cylinders. In the experiments the behavior of each form was studied under varying flow conditions, from initial movement to movement under high velocities. Figure 10 shows the results for a selected set of particles. The vertical axis of the graph shows the ratio of particle velocity to water velocity, and the horizontal axis is a non-dimen-

sional number, the Froude Number,[4] which represents the flow conditions. In general, the larger the Froude Number on the graph, the higher the velocity and the energy state of the fluid in these experiments.

The graph for spheres (the heavy solid line) indicates that no movement occurred until a critical energy state was reached, represented by F_c, at which point movement began abruptly, with a velocity 0.4 that of the water. At increasing water velocities the ratio increased, rapidly at first, and then more slowly, toward a limiting value of about 0.9. The lighter lines in the figure repre-

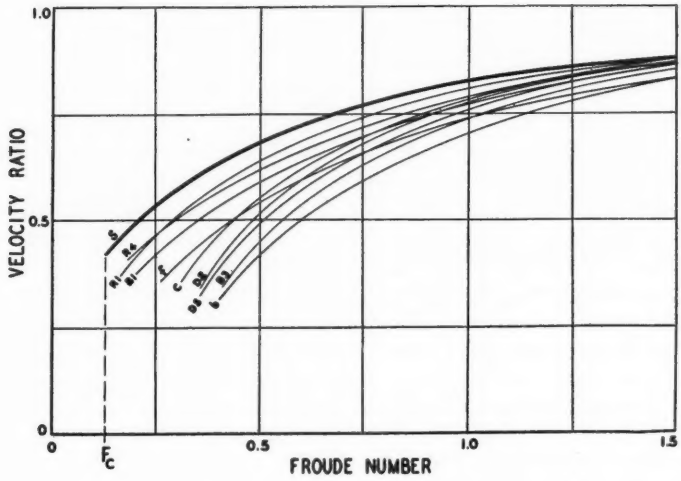

FIG. 10.—Non-dimensional graph of particle movement in flume. Letters refer to forms stippled in Figure 9.

sent other forms of lower sphericity and indicate that each one has a similar behavior pattern. Motion begins at successively higher energy states, and at lower initial velocity ratios, but toward the limiting value all the curves merge to about the same limit. The distribution of the curves is almost wholly a function of the sphericity, and is essentially independent of roundness. Thus in the dynamics of particle movement as well as in the dynamics of abrasion, the sphericity is more fundamental than the roundness.

An interesting feature of Figure 10 is the insight it affords into the conditions of selective transport during traction movement. At low values of the Froude

[4] The Froude Number is a non-dimensional flow parameter which summarizes flow conditions when gravitational or inertial forces are more important than viscous forces. It is expressed as $v/\sqrt{gy}$, where v is the velocity of the fluid, y is the depth, and g is the acceleration due to gravity. For details of the Froude Number and other non-dimensional flow parameters, see Rouse (23), chapter 1.

Number the several curves spread out, whereas at large values they all merge into a common trend. Thus the chances of shape selection are best at low energy states, whereas at high energy states all the particles move regardless of shape. (The same situation holds for size selection, as other data show, but space limitations prevent the development of the theme here.) In short, selective transport during traction at least is a function of low velocities whereas large mass transport is a function of high velocities. This principle is amply illustrated by the flood deposit of Figure 2, which is poorly sorted with respect to size at least. During floods the discharge, velocity, and energy state of the stream are large; the lower energy state of the stream since the flood has resulted mainly in some reworking and better selection of the poorly sorted flood deposits.

Knowledge of the dynamic aspects of sphericity and roundness is by no means complete, but as knowledge increases, it narrows down the interpretive phases of these properties. It appears safe to say at present that sphericity is an important dynamic attribute of particles, whereas roundness is a second order factor in some aspects of particle behavior. Roundness is a very sensitive index of abrasion in the early stages of particle wear because corners and edges can be worn down with only slight changes in sphericity and size. However, the higher the value of the roundness, the more slowly does it increase, so that beyond the initial stages there may be relatively little diagnostic value to this property. The picture is partly clouded by the fact that during selective sorting by size or shape, particles of low roundness may outstrip those of higher value, if low roundness is associated with the selected particles. Thus, apparent reversals of rounding may be observed (24). Although data on the subject are scant, it is the writer's present opinion that in most normal processes of sedimentation the selective effects are far more important than the abrasive effects in accounting for observed changes in size and sphericity, and perhaps even roundness.

Progress in the study of sphericity and roundness has been paralleled by progress in other particle attributes. Particle size has been the subject of considerable dynamic study, much of which is in the engineering literature (23, chapter 14, discusses the larger aspects). Particle orientation has been extensively studied recently (25, 26); and work on the mineralogy of sediments is relatively advanced (27, 28, 29 are examples of trends). Perhaps the most neglected field from a quantitative point of view is surface texture, which affords an excellent field for research. As work on particles progresses there is an increased recognition of the inter-relations among particle properties, with a growing realization that all the properties of particles may require consideration in sediment interpretation. It is established, for example, that in both traction and suspension transport the settling velocity of the particle is of basic importance. Settling velocity in turn depends upon the size, shape (sphericity), and density of the particle, so that these three properties control particle behavior under given dynamic conditions. Sorting may take place on the basis of any of these three. Size is probably the most common basis of selection, but shape and density may be even more

important in special circumstances. Roundness and surface texture, on the other hand, are of little significance in particle transport, but angular particles respond rapidly to abrasion, and surface texture responds to abrasion and solution. Roundness is important in questions of distance from source, and surface texture may reflect, among other things, some post-depositional changes. Heavy-mineral studies shed light on source areas and post-depositional changes. Particle orientation, finally, is a function of other particle properties and of the conditions of transportation and deposition (30). The significance of particle properties, in terms of those most affected by abrasion or most directly concerned with the selective process, is given in the following table (31), in which XXX represents a strong effect, and — is negligible.

Property	*Abrasion*	*Selective Transport*
Size	X	XXX
Shape (sphericity)	X	XXX
Density	—	XX
Roundness	XXX	—
Surface texture	XXX	—
Orientation	—	?

As work on particle properties continues, relations among the several properties help explain observed variations. The relations between size and roundness, or between roundness and sphericity, shed light on problems of abrasion and selective transportation. Pettijohn (4) discusses a number of the inter-relations; some field examples are given by Pettijohn and Lundahl (32).

Paralleling the development of quantitative techniques for studying particle properties are methods of graphic presentation and statistical analysis. At present there is little tendency toward complete standardization of statistical methods, but considerable progress has been made toward the recognition that conventional statistical devices, tied in with the background of statistical theory, are to be preferred to arbitrary measures. Quartile and moment measures (12, chapters 8 and 9) are on the whole superseding such measures as equivalent grades and fineness moduli. The popularity of the quartile approach rests partly on its graphic nature, but recent developments in graphic determination of moment data by Otto (33) largely eliminate this factor. The development of statistical thinking has followed a path similar to that of particle properties, inasmuch as the stages include the setting up of definitions, the development of graphic or computational techniques, the study of the geometrical meaning of the measures, and finally their use in the dynamic study of sedimentary processes. It was discovered also that the same kinds of statistical measures developed for particle size applied equally well to sphericity, roundness, and orientation, so that a common background of geometrical principles applies to all.

An extension of the quantitative study of particles is the study of mass properties of the sediment, which depend upon the aggregate of particles. Here are included porosity, permeability, color, compactibility, *et cetera*. Each of these is a

function in part of the individual particle properties plus such added factors as degree of packing, water content, and so on. The relation of the mass properties to the individual properties is only partly known, and although mass properties may usually be measured directly, an understanding of their degree of dependence on particle properties aids considerably in the interpretation of mass variations in sediments. For example, it is possible for the permeability to increase as the average particle size decreases, providing the sorting improves at a certain rate with decreasing size (34). In similar manner, the dependence of mass properties on variations of particle shape and orientation offers fertile fields for study.

Extension to environments of sedimentation.—In the final analysis, it is not until the quantitative approach is explicitly applied to environments of sedimentation that a complete understanding of the dynamics of sedimentary variation can be achieved. In addition to the progressive changes which occur in particle properties due to abrasion and selective sorting, variations occur in such mass properties as porosity, permeability, thickness, faunal content, organic carbon content, and other features. By relating these changes to the physical and chemical conditions of the environment, as well as to energy transformations in the environment, a more dynamic picture of sediment behavior can be obtained.

One approach to dynamic environmental studies can be made by adopting the "closed system" point of view of the more exact sciences. By definition a closed system is one in which the boundary conditions and the total energy of the system are known, and in which the transformations of matter may be observed and measured. Typical sedimentary environments which may be studied by such an approach include drainage basins, beaches, tidal lagoons, lakes, bays, dune areas, *et cetera*. In each system the boundary conditions may be defined by the limiting land forms, although any environment or part of an environment may be defined by arbitrary bounds, providing that the flow of energy and materials across the boundary is included in the study. In a typical environment the sediment is derived from some source; it is carried from the source to the point of deposition by some agent; and the agent which carries it is energized in some manner or other. During the process both erosional and depositional land forms are developed. Thus the study of any environment includes a study of the following three factors:

1. The boundary conditions of the system
2. The materials of the system
3. The energy of the system.

The boundary conditions and the energy flow set the conditions for sedimentary phenomena within the environment. The boundary conditions are important in controlling the distribution of energy within the environment, and they themselves may be changed by the very processes which they confine. Continued erosion along points of high energy application and deposition elsewhere may change the boundary conditions sufficiently to modify the energy pattern, thus progressively modifying the details of the processes. The materials

in the environment are selectively sorted and abraded during their movement, and the nature and extent of the movement are controlled by the energy pattern and the boundary conditions. Thus all three factors are intimately related, and through their mutual interaction the sediments are distributed in typical patterns over the environment. These patterns of sedimentary characteristics, then, should directly reflect the dynamic conditions of the environment; that they do is taken as a basic assumption in all sedimentary studies.

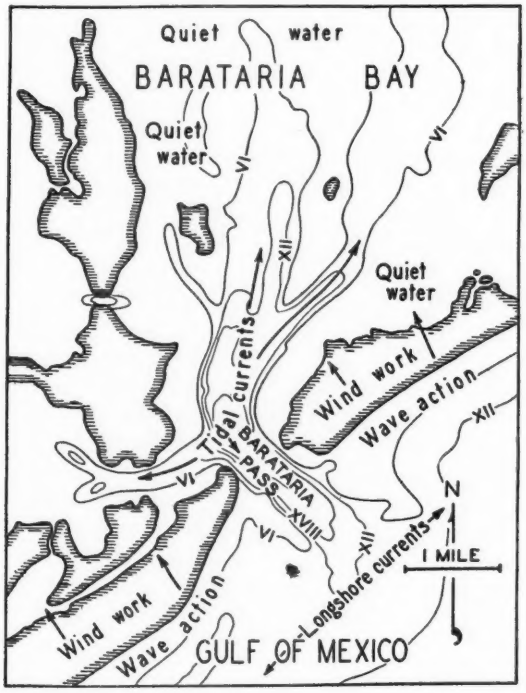

FIG. 11.—Portion of Barataria Bay, Louisiana, showing geological processes.

That the assumption holds can be demonstrated qualitatively, and it could be more rigorously demonstrated if data were at hand to construct an energy-flow pattern for any given environment. By expressing the energy as its gradient, a map could be constructed showing the areas in which the energy is used either in moving the sediments or in turbulence or similar phenomena. The writer knows of no such map in the literature, but it is possible to visualize an example from the situation shown in Figure 11, which is a portion of Barataria Bay (31). The several geological agents which operate in the environment are indicated. Wave

energy from the Gulf is concentrated along the barrier beach, and current action due both to waves and tides is prominent in the nearshore zone. In addition, tidal currents move into and out of the bay through the inlet, and follow the channels within the bay. Away from the channels in quiet water little work is done in shifting the sediments. Finally, wind work is effective across the barrier in moving and re-sorting the beach sand.

The representation of the energy flow would require three diagrams, one for each agent (waves, currents, wind), but if the wind work is neglected, the other

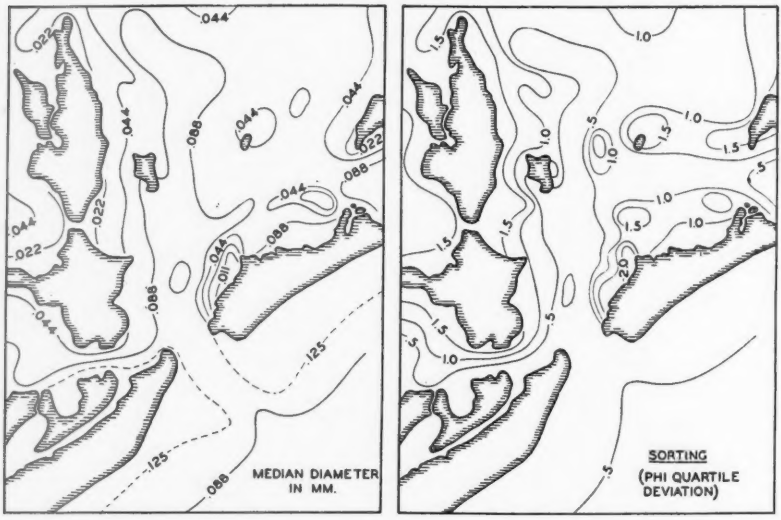

FIG. 12.—Sediment maps of Barataria Bay. *Left*, average size (medians); *right*, sorting index (logarithmic).

two could be combined into an approximate map which would show lines of equal energy dissipation arranged roughly parallel with the Gulf shore, with increasing values toward the barrier, and with the highest area along the barrier to represent the large energy losses in the zone of breaking waves. Lines of equal energy dissipation would also enter the inlet and extend along the channels, diminishing in value along the channels and to the sides. Thus the net result would be a map with its lines of highest value along the barriers; with intermediate values in the Gulf section and along the channels; and with lines of least value in the quiet waters of the bay. The pattern would resemble the depth lines in Figure 11, except that the energy losses along the channels are greater than in the quiet water, whereas the channels themselves are deeper than adjacent parts of the bay.

The degree to which these dynamic conditions are reflected by the sediments is shown in the maps of Figure 12 (31), which indicate the variations of average sediment size and degree of sorting over the environment. The maps were made by collecting bottom samples on a grid system laid over the bay, analyzing them, and plotting the corresponding size and sorting values at the sampling sites. Lines of equal value were then drawn through the points, which yielded the patterns shown. An examination of the maps in terms of the energy discussion shows a fair agreement, and demonstrates that the coarser and better sorted sediments are associated with areas of higher energy application, whereas the finer and less well sorted sediments are associated with areas of lower energy loss.[5] If it is universally true for environments that patterns which reflect the dynamic conditions agree with patterns of sedimentary properties, an important point is gained, because then from ancient sediment patterns it should be possible to reconstruct energy flow and energy losses within ancient environments. That this is likely to be the case is suggested by the fact that much of the energy in natural sedimentary processes is dissipated through friction, so that the essentially kinematic patterns of sediment distribution may well yield the corresponding dynamic patterns.

The relations between sediment patterns and energy or process patterns afford an insight into the combinations of factors which produce sediments of given characteristics. It is well known that a single environment may produce a variety of sediments, and that different environments may produce the same kind of sediment at least locally. An understanding of the laws which govern these differences or similarities will inevitably furnish a basis for more universal principles of sedimentation than are now available. It is also possible that areas of greater energy dissipation are closely related to areas in which the most rapid sedimentary changes occur, and these in turn may be directly or reciprocally related to favorable sites for oil localization due to stratigraphic causes. Complexities enter the picture when the methods are applied to ancient sediments because post-depositional changes and other factors may locally control the situation; this point is discussed later.

The present state of knowledge in sedimentation may be summarized as one in which facts are accumulating at a faster rate than present principles can absorb them. The result is a series of apparent contradictions and a state of flux in sediment interpretation. To a large extent it is not yet recognized that the variability of some sedimentary phenomena over short distances is not an indication that the sediments are chaotic, but rather that the scale of the variations is smaller than our sampling interval. The problem is essentially statistical, and sampling theory can be used to solve the problem of the proper interval to disclose variations or trends (35, 36, 37). As the quantitative approach furnishes a better understanding

[5] This relation does not contradict the earlier discussion regarding selection at low energy states. The areas of maximum energy dissipation in the present example correspond with low or intermediate values of the Froude Number in Figure 10, and in addition, problems of both traction and suspension transport enter the Barataria Bay picture.

of the dynamics of sedimentary behavior, it will be recognized that what appear to be contradictions of fact may be in some instances deviations about an unknown average, due to large or small scale variations in the dynamic conditions. The net result should be an increasingly integrated group of facts, with present principles modified or broadened to account for present apparent discrepancies. There is little question that the trend toward more complete quantification of sedimentary data will continue, especially as knowledge already gained becomes absorbed into current geological thinking.

Progress in theoretical sedimentation becomes valuable in applied fields of geology when the theoretical data are translated into forms which may be directly used. A theoretical equation may be of little direct value unless it is implemented with techniques or devices which permit its application to a variety of problems. The recent trend toward much more rapid methods of sedimentary analysis is a step in this direction. Another is the increasing realization that the data of quantitative sedimentation are mappable.

2. APPLICATION OF QUANTITATIVE DATA TO APPLIED PROBLEMS

Contour-type map and its properties.—In a recent article Kay (38) presented a classification of maps for stratigraphic and structural studies. His grouping includes the following types.

Paleogeographic maps
  Paleogeomorphic maps
  Paleolithologic maps
  Paleobathymetric maps
  Paleoclimatologic maps
  Paleo-oceanographic maps
Isopachous maps
Paleogeologic maps
Palinspastic maps

According to Kay, a map is geographic if it portrays conditions at a single time, and stratigraphic if it covers a span of time. Maps which present quantitative sedimentary data may be in either category, depending upon the quantities measured. A map of the size distribution of bottom sediments within a bay may be geographic, whereas a map of the thickness of an ancient deposit may be stratigraphic because it covers the entire time of deposition. Distinction between the two types may be difficult in a given instance, but on the whole the maps to be discussed are geographic rather than stratigraphic.

When characteristics of sediments can be converted to numbers, they may be used to prepare contour-type maps of the kind illustrated in Figure 12. These maps, which have lines connecting points of equal magnitude, are properly referred to as "isopleth" maps, but in terms of Kay's classification they are in the paleolithologic group, and the lines are called "isoliths" (39). An isolith is a line of similar lithology based on color, texture, or composition. Isolith maps may range from generalized forms showing the distribution of rock facies to detailed maps based on numerical data. In the present discussion such maps are not con-

fined to ancient sediments, as the term paleolithologic implies; the term isolith of course has no age connotation. Kay includes isopach maps in a separate category whereas such maps are also isopleth maps inasmuch as lines are drawn through points of equal thickness. Thus the present discussion cuts across Kay's grouping to some extent, and merely reflects the fact that his classification is

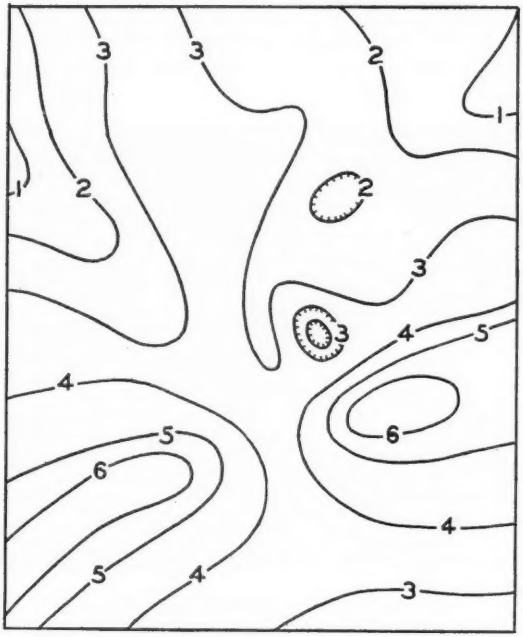

FIG. 13.—Generalized contour-type map. Numbers arbitrary, to indicate relative values of lines.

based upon use, whereas the writer's treatment is based upon similarity of construction and of geometrical properties.

The necessary data for constructing contour-type maps include a series of values of a given variable (average size, thickness, *et cetera*), each associated with a specific geographic and stratigraphic location. The known values should be spaced closely enough over the area to bring out at least the overall trends in the data. The geometrical properties of all such maps are the same as those of an ordinary contour map, so that the same principles of geometrical interpretation can be used, with due allowance for the differences in the physical attributes shown on the map. Figure 13 is a generalized contour map, with arbitrary numbers to indicate the direction of increasing values. If the numbers represent eleva-

tions it is an ordinary contour map; if they represent thickness of sediment it is an isopach map; if they represent average particle size it is a size map, and so on. The important point is that in each instance the lines are lines of equal magnitude or quantity, and they are related to their neighbors by some constant difference, sum, product, or power. Hence each map represents a surface, with the spacing of the lines inversely proportional to the slope of the surface. Figure 14 is a model of the surface corresponding with Figure 13. It is a very generalized size surface of part of Barataria Bay (roughly the central part of Figure 12, *left*) and is so constructed that the height of any point above the base is proportional to the

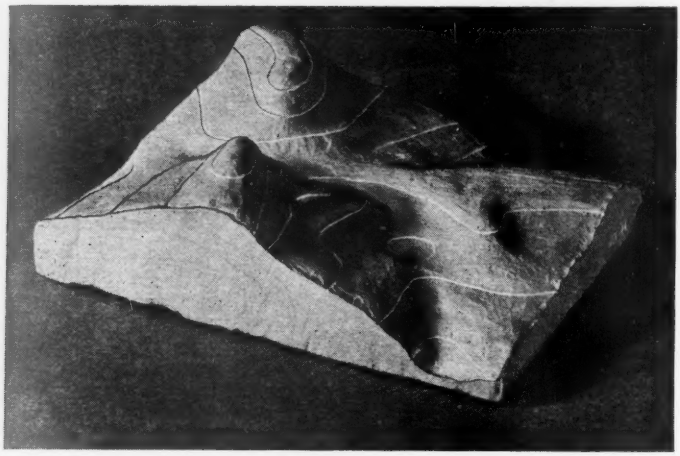

FIG. 14.—Model of generalized map of Figure 13.

average particle size of the sediment at that point. The coarsest sediments may be seen along the barrier, with the tongue of intermediate sizes extending along the lagoon channel from the inlet, and the finer sizes off to the sides and locally near the inlet.

Surfaces such as these have certain geometrical properties also. For example, if Figure 14 were a landscape, rainwater falling upon it would run downslope at right angles to the contours, because a line normal to the contour at any point is the direction of maximum slope at that point. By drawing a series of normals on such a surface or its map, Figure 15 is obtained, which shows the lines of maximum slope superimposed on the lines of equal magnitude. For a land surface these arrows indicate the directions of surface runoff; for other sediment properties the lines of steepest slope may also have a physical significance. For example, if Figure 15 is a size map, then the directions of most rapid change of permeability extend upslope along the slope lines. This relation follows from the fact that

permeability increases as the square of the average diameter (34) and the diameters increase most rapidly upslope. Thus it would be possible to construct a permeability surface from the size surface if average sorting were known, and in the absence of cementation. In fact it is interesting to note that the several surfaces representing various dynamic attributes of the sediments would all be similar, and would differ mainly in steepness and height. Thus Figure 14 is also

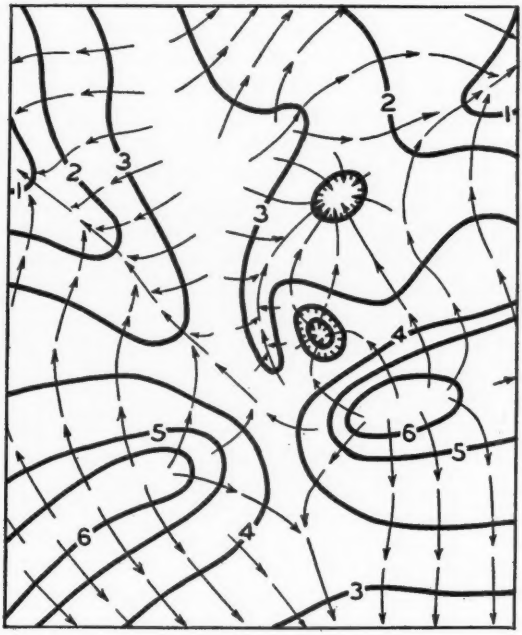

FIG. 15.—Lines of maximum slope superimposed on generalized contour-type map.

a surface of the energy dissipation in the environment, as may be seen by recalling the earlier discussion.

In some instances at least it is also possible to apply reasoning based on the theory of the potential to such surfaces. Potential theory finds wide application in hydrodynamics, electricity, magnetism, and heat flow. A velocity potential, for example (23, chapter 4), is a quantity or function whose rate of change in any direction is the component of the velocity in that direction. Moreover, the direction of motion is always normal to a surface of constant velocity potential, so that the potential surface cuts all streamlines at right angles. Thus where the reasoning applies, the contour lines represent the potential surface and the lines of maximum slope correspond with the streamlines. The significant point is that

where the relation holds rigorously the background of reasoning associated with potential theory may be woven into the map interpretation. In those instances the contour surface based on a given variable will have associated with it some other physical concept related to the slope lines. The writer plans to develop this topic more fully at a later date.

An important point in the extension of contour-type maps to sedimentary data is that although the preparation of such maps may require training in sedimentary technique, the interpretation of the maps follows standard lines of geometrical reasoning. Hence the general geologist, skilled in map interpretation, may find much of value from the maps in conjunction with other geological data bearing on his particular problem. Just as a series of principles has been developed for the interpretation of contour maps of land surfaces, so may a similar set or sets be developed for the study of sedimentary maps. In using such maps to narrow down exploration possibilities for stratigraphic or sedimentary traps, for example, it may well be that particular groupings of the sedimentary contours may be significant. Where rapid changes in sedimentary attributes result in closer spacing of the lines, they may indicate that other features are changing rapidly also. In short, it may be the steeper slopes or the margins of the steeper slopes which may be significant in the search for sedimentary-stratigraphic oil. Moreover, these areas of rapid change may show typical closed lines, so that "attribute highs" instead of structural highs, may afford the magic closed contour for sedimentary-stratigraphic exploration.

Classification of contour-type sedimentary maps.—Contour-type (isopleth) maps of sedimentary data range from general maps presenting an overall picture to detailed maps of specific attributes. A stratum of sandstone may be converted into values of thickness, mean size, sorting, heavy mineral content, permeability, *et cetera*, and each of these used as the basis for a contour-type map. Such maps are factual in that they present the observed areal variation of a chosen attribute, but more or less interpretation is necessarily included because incomplete data may require interpolation or extrapolation. Similarly, when a thick section is used as the basis for the map, the average values inject a stratigraphic element into the maps, which may indeed be advantageous in some studies.

The following classification indicates the range of possibilities in contour-type maps of sediments. The classification is not to be considered a rigid system; the groupings are made to suggest family relationships rather than categories into which a map either falls or does not fall. Examples are cited in each group, but the particular literature references are mainly illustrative. Some of the data have never been presented in map form as far as the writer is aware, but their unquestioned inclusion in the general classification suggests their possible usefulness for shedding additional light on sedimentary and allied problems.

a. Generalized regional maps.—This group includes maps which show regional features, usually generalized and on a small scale. Strictly speaking, such features

should be shown as lines of equal magnitude to be classified here, but there is necessarily an indefinite limit to the class. A map of sediment variation showing areas of clastic and non-clastic facies separated by an isolith is a very generalized contour map with one contour line. Regional stratigraphic maps, which show by gradations the areas of lime, shale, and sand, belong here; such data could be expressed as lines of equal percentage of lime, shale, or sand in the section. Hale (40) shows the lithologic changes in the lower Mississippian limestone of western Michigan, based partly on glauconite content. In this group belong also paleogeographic maps which can be constructed on lines of equal value; Jager (41) has an example of a paleogeomorphic map.

b. Maps of particle properties.—Here are included a large group of maps which show the areal variations of measured attributes of sedimentary particles. Size,[6] shape (sphericity), roundness, surface texture, and orientation (petrofabrics) are generally recognized as the more significant. Mineral properties are treated separately below. Particle maps may indicate not only average values of the particle attributes, but also a host of other statistical parameters. For each particle property there is an average, a measure of spread ("sorting"), a measure of asymmetry (skewness), and a measure of peakedness (kurtosis). Surface texture cannot at present be expressed numerically, but lines of equal percentages of polished or frosted grains could be drawn. Maps of size attributes are most common, but others are beginning to appear. Shepard and Cohee (42) and Pye (43) show average size maps; Krumbein and Aberdeen (44) present a sorting map; Krumbein and Griffith (45) have a skewness map; and the same paper contains a map of average particle sphericity. The writer knows of no maps in the literature which present particle roundness or orientation.

c. Maps of mass physical properties.—This group includes maps based on aggregate properties of sediments, such as porosity, permeability, color, average density, and thickness.[7] Some geophysical maps are included in this group, to the extent that they indicate average physical properties through a section. Maps of the areal variation of seismic wave velocities or the electrical properties of a stratum are examples. Isopach maps are the most common in this group (Lee, 46, has examples) and although permeability maps are frequently used, the writer knows of only one (47) in the literature.

d. Maps of mass chemical properties.—A large number of maps is possible in this category, inasmuch as any measurable chemical attribute may be mapped. One may map the percentage variation of a given element, for example, or of a given compound. Various ratios, as the Ca/Mg ratio or its reciprocal, may be useful in indicating the change from limestone to dolomite, with all the implications which such change includes. Maps of insoluble residues (48); of degrees of

[6] Shepard and Cohee (42) introduced the term "isomegathy" for lines of equal average particle size. The writer is non-committal about the development of individual names for each of the infinite variety of contour-type maps.

[7] Some isopach maps may be more appropriately classified in group *a* than here.

cementation (49); of radioactive content; of organic carbon content (50); isocarb maps (51); and many other possible types, are included here.

e. Maps of mineralogical properties.—Heavy-mineral data lend themselves well to the preparation of contour-type maps. The percentage of heavies (52); or the percentages of particular species; or ratios among various species (say non-resistant to resistant) may yield interesting information. Smithson (53) plotted certain diagnostic minerals to study the effects of post-depositional changes on mineral patterns. The cementation map mentioned in *d* may be included here if the mineral content of the cement (calcite *versus* quartz, for example) is emphasized. The facies change map of Hale (40), mentioned in the first group, could presumably form the basis for a map showing lines of equal glauconite content.

f. Maps of associated geological processes.—This group includes maps of the type mentioned in connection with Figure 11, showing the energy conditions within an environment. Maps of wave refraction give evidence of energy flow to a shore or beach (54, p. 75, is an example). Maps of current distribution, velocity variations, and the like, may be valuable for indicating relationships with sediment patterns. For example, a map of the detailed variations in flow parameters of a stream, related to a map of average sediment size, may account in part for the observed rapid areal variations in stream deposits. Maps of energy distribution and dissipation are necessarily confined to modern environments, but in some instances they may be reconstructed from sediment patterns, as pointed out earlier.

g. Maps of associated fauna and flora.—Many biologic and paleontologic features can be presented on contour-type maps. Examples which suggest themselves include maps with lines of equal population density (number of fossils per unit volume of sediment) based on whole faunas or particular species. Maps of variations in faunal assemblages, expressed numerically as percentages or otherwise, from fresh to salt water in an estuarine environment, would be instructive in indicating degrees of variation and overlaps. Such maps would prove useful in establishing principles of correlation across facies changes. The writer is not aware that maps in this group have been published. Maps by Davis (55) of the distribution of species on the Tortugas Keys, and maps by Foerste (56) of the distribution of fossils, are approaches to this type, but they do not show lines of relative abundance.

h. Maps of associated fluids.—The fluids contained within the sediments constitute part of the sedimentary or post-depositional record. Per cent saturation of pore space with oil, gas, or water, are examples. The A.P.I. gravity of the oil or the specific gravity directly, afford instructive maps. The earliest example, based on Beaumé gravity, was published in 1919 by Tough, Willison, and Savage (57). This map is reproduced here as Figure 16; it is interesting in connection with the earlier discussion because it resembles a landscape with valleys and hills and illustrates the underlying geometrical similarity of many contour-type maps. Plummer and Sargent (58) show maps of equal salt content of Woodbine sand

waters; Schneider (59) has a map of edgewater relations; and Shea (60) shows maps based on the percentage of water produced with the oil. Bottom-hole-pressure maps are common (Weeks and Alexander, 61, show examples); other maps include initial yields of open flow lines. The chemical constituents of gas or oil

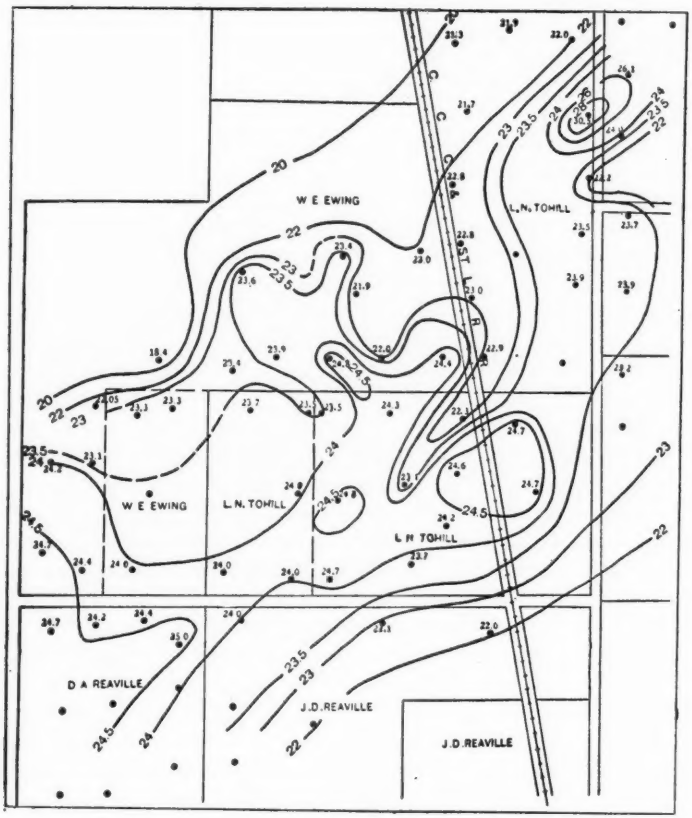

FIG. 16.—Map of Beaumé gravity of oil in Flat Rock pool, Illinois (57), to illustrate landscape-like quality.

furnish the basis for yet another series of maps (62); and Price and Headlee (63) have a map of the thermal value of natural gas. Many of these maps are used for engineering and reserve-estimate purposes, but it is obvious that such maps can aid in solving sedimentary problems also. Geochemical exploration maps which show lines of equal hydrocarbon content of soils or sediments, belong to this group also.

i. Maps of associated structures.—Sediments are commonly discussed in terms of texture, composition, and structure. Among structural features of sediments are bedding, cross-bedding, ripplemark, concretions, *et cetera*. Maps based on ripple orientation or on the orientation of cross laminations (64) may bear on directions of currents, shoreline trends, and the like, as Kay (38) points out. Maps of the structural attitude of the sedimentary beds also belong here; the widely used structure-contour map is an example.

j. Maps of attribute combinations.—Several ratio maps have been mentioned, such as the Ca/Mg map, but there is a whole series of maps based on combinations of properties (sums, differences, products, ratios), not necessarily within any single group of attributes. Thus, Weeks and Alexander (61) show a map based on the product of porosity and sand thickness. The map of cementation by Torrey (49), mentioned earlier, has on it the initial yields of wells, which expresses the combination idea, although no ratio or product was used. Other maps may be based on non-dimensional ratios, such as average particle size divided by thickness, or permeability in darcys divided by thickness squared. The direct comparison of a series of individual maps serves some of the same purposes as the combination maps, but the combination maps may bring into bolder relief contrasts or similarities among attributes, thus focussing attention on particular areas. As in all other fields of geology, it is the convergence of evidence which is important. An isopach map may show some relation between thickness and known occurrence of oil, but the data are strengthened if maps of permeability, cementation, average particle size, and others, are available. The writer has suggested that it would be profitable to examine a known petroliferous area or stratigraphic pool by plotting the known occurrence of oil on a whole series of sedimentary maps to detect some of the factors which may have controlled the localization of the oil. Although such a study may be largely historical in terms of oil, two possible byproducts may be the discovery of additional prospects in the same area, and a set of principles which could be used in exploring new territory.

Perhaps the main point to be emphasized in this presentation is that there exists a large family of maps of sedimentary attributes, many of which have already demonstrated their usefulness. The writer submits the thesis that other, as yet unmapped attributes, may prove equally useful by reflecting the dynamic conditions of sedimentation or significant post-depositional changes. It is not possible, in the present state of knowledge, to predict which particular maps will be most significant in a given situation.

Maps of recent and ancient sediments.—No distinction was made between maps of recent and ancient sediments in the preceding discussion. The study of recent sediments has the great advantage from a theoretical viewpoint that the medium of transportation and deposition is still present, and the flow of energy and materials over the environment may be directly observed. Moreover, samples may be collected at intervals as small as desired, and problems of post-depositional change are negligible. Work with ancient sediments, on the other hand, is handicapped by

a lack of sufficient samples; by the complete absence of the agents which produced the deposit; by post-depositional changes in composition and texture; by erosion and dislocation of the strata; and by problems of correlation. As far as possible the post-depositional features must be eliminated to obtain the original patterns of sediment variation, and the environment of deposition must be wholly reconstructed by inference.

Some workers in applied geology are of the opinion that ancient sediments should be studied in preference to recent ones, on the ground that the results will be more directly applicable to the search for oil. However, it is only from a study of recent sediments that undistorted variation patterns can be obtained and be directly related by observation to the dynamic environmental factors. The patterns of modern environments and their sediments furnish the basis for evaluating ancient patterns and for eliminating or correcting for some of the post-depositional changes. An ideal arrangement would be to have a wide background of factual and theoretical data available on recent environments which could be drawn upon for the interpretation of ancient patterns. Thus, more complete knowledge of what takes place in a present-day tidal lagoon environment in terms of energy processes and sediment variation, as well as of faunal assemblages, would be of inestimable value in the exploration of similar environments of the past.

CONCLUDING REMARKS

This paper contains numerous philosophical remarks which may not be appropriate to a scientific paper. However, during his lecture tour the writer sensed the need for an over-all presentation which would help crystallize the point of view which leaders among petroleum geologists have advocated: the need for new ways of thinking about oil discovery. The writer was encouraged in preparing this paper by numerous suggestions and by the favorable response of his audiences. Some changes have been made in the manuscript version, but the underlying point of view remains the same.

The writer intends no implication that sedimentation alone affords the key which will unlock the door to sedimentary-stratigraphic traps, but he does insist that there remain many lines of attack which have the known merit that they will shed additional light on complex sedimentary problems. To the extent that such new light is integrated with stratigraphic and paleontologic evidence, and is absorbed into current geological thinking, it may well contribute to a renaissance of geological methods for finding oil.

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MARINE JURASSIC FORMATIONS OF SWEETGRASS ARCH, MONTANA[1]

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ABSTRACT

The marine Jurassic rocks of the Sweetgrass arch in western north-central Montana have been assigned to the Ellis formation. As a result of measuring and sampling eleven Jurassic sections around the Sweetgrass arch and from examining numerous well cuttings, the writer concludes that the Ellis consists of three major lithologic divisions that should be recognized as formations, and that the Ellis should be raised to group rank. The formations of the Ellis group from oldest to youngest are herein named Sawtooth, Rierdon, and Swift.

The Sawtooth formation consists of three members, a basal fine-grained sandstone, a medial dark gray shale containing a few dark limestone beds, and an upper member of light gray calcareous siltstone, fine-grained sandstone, or sandy, oölitic limestone. The Sawtooth is as little as 8 feet in thickness on the Kevin-Sunburst dome. It thickens eastward to 200 feet in the Sweetgrass Hills and westward to about 200 feet along the Rocky Mountain Front. The formation is absent over most of the South arch. The lower two members pass into redbeds east of the Sweetgrass Hills and on the southeast flank of the South arch.

The Rierdon formation consists mainly of gray limy shale and nodular limestone. It seems to overlie the Sawtooth formation conformably. It is as little as 72 feet in thickness on the Kevin-Sunburst dome, but thickens eastward to 180 feet in the Sweetgrass Hills and westward to about 200 feet along the Rocky Mountain Front. The formation is absent over most of the South arch.

The Swift formation is composed of two members along the Rocky Mountain Front and eastward across the Kevin-Sunburst dome at least as far as the Sweetgrass Hills. The lower member is dark non-calcareous shale, highly glauconitic at the base. The upper member is gray fine-grained flaggy glauconitic sandstone containing abundant black-gray micaceous shale partings. On the South arch the formation consists of fine-grained flaggy sandstone which is locally pebbly at the base. In the vicinity of the Little Belt Mountains the formation is massive fine-grained sandstone containing a prominent basal conglomerate. The Swift attains its maximum thickness of 166 feet in the Pondera field. The formation has been removed by pre-Kootenai erosion from most of the Cut Bank area, and from a sma'l area west of the Whitlash field.

All the formations are fossiliferous. According to Imlay, the Sawtooth is upper Bathonian, the Rierdon is upper Bathonian and Callovian, and the Swift is Divesian and Argovian.

The South arch was an island through most of the Bathonian and Callovian stages. At the close of the Callovian the marine waters retreated from the area. During the early Divesian the Sawtooth and Rierdon formations were locally thinned by erosion and possibly removed from some areas. Later in the Divesian marine waters transgressed the entire area and remained until the close of the Argovian.

INTRODUCTION

All, or most, of the marine Jurassic rocks of the Sweetgrass arch in western north-central Montana have been assigned to the Ellis formation. The Ellis rests unconformably on marine Mississippian beds and is overlain conformably by Upper Jurassic continental deposits (Morrison) or unconformably by Lower Cretaceous continental deposits (Kootenai). Geologists have had little or no difficulty in delimiting the base of the Ellis over most of the Sweetgrass arch. In contrast, the upper boundary has been placed at a number of stratigraphic levels. In the southern part of the area continental Upper Jurassic beds have been included with the Ellis, and in the northern part, the upper boundary of the Ellis has been drawn so low as to exclude some marine Jurassic rocks.

[1] Manuscript received, May 12, 1945. Published by permission of The Carter Oil Company.

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Five important factors have led to confusion in the interpretation and correlation of the Ellis. First, the southern part of the Sweetgrass arch remained a positive element throughout the Bathonian and Callovian stages, whereas the rest of the area received sedimentation during that time. Second, the nature and extent of the Callovian-Divesian unconformity has not been pointed out by previous workers. Third, facies changes, particularly the presence of red sediments on the east side of the Sweetgrass arch, have not been clearly understood. Fourth, lithologic similarity between black chert sandstone in the upper part of the Ellis and black chert sandstone forming the base of the Kootenai on the northwest flank of the Sweetgrass arch has led to the correlation of these sandstones. Fifth, the nature and extent of the Ellis-Kootenai unconformity has not been treated adequately by previous writers.

It is the purpose of this report to show that the marine Jurassic rocks of the Sweetgrass arch compose three distinct formations. The oldest formation, herein named the Sawtooth, consists of sandstone, siltstone, shale, and limestone of Bathonian age. The medial formation, herein named the Rierdon, consists of limy shale and nodular limestone of upper Bathonian and Callovian age. The youngest formation, herein named the Swift, consists of sandstone and non-calcareous shale of Divesian and Argovian age. Continental beds included in the Ellis by some geologists are assigned to the Morrison formation in this report. The writer proposes to raise the Ellis to a group, and to restrict that name to marine Jurassic beds.

The field work was conducted during parts of the summers of 1942 and 1944. Six Jurassic sections were measured and sampled along the Rocky Mountain Front from Badger Creek in Sec. 3, T. 29 N., R. 11 W., southeast to the vicinity of Craig in Sec. 16, T. 15 N., R. 3 W. Four Jurassic sections were measured along the northern flank of the Little Belt Mountains. One section was measured in the Sweetgrass Hills, on Sage Creek in Sec. 8, T. 36 N., R. 5 E. Sections were measured outside the area covered in this report on the east side of the Bearpaw Mountains and in the vicinity of Marias Pass near the southern boundary of Glacier National Park. The information derived from the Bearpaw and Marias Pass sections has been useful in the preparation of the isopach maps. Some of the measured sections were reviewed in the field with R. W. Imlay and J. B. Reeside, Jr.

Cuttings from many wildcat and field wells drilled for oil and gas in the area of the Sweetgrass arch were examined critically with a binocular microscope. The samples were excellent inasmuch as the Ellis was reached at relatively shallow depths and most of the wells were drilled by cable tools.

ACKNOWLEDGMENTS

The writer is deeply indebted to R. W. Imlay, paleontologist of the United States Geological Survey, for his age determinations of the Jurassic formations, suggestions as to formation nomenclature and correlations, and for many other helpful suggestions.

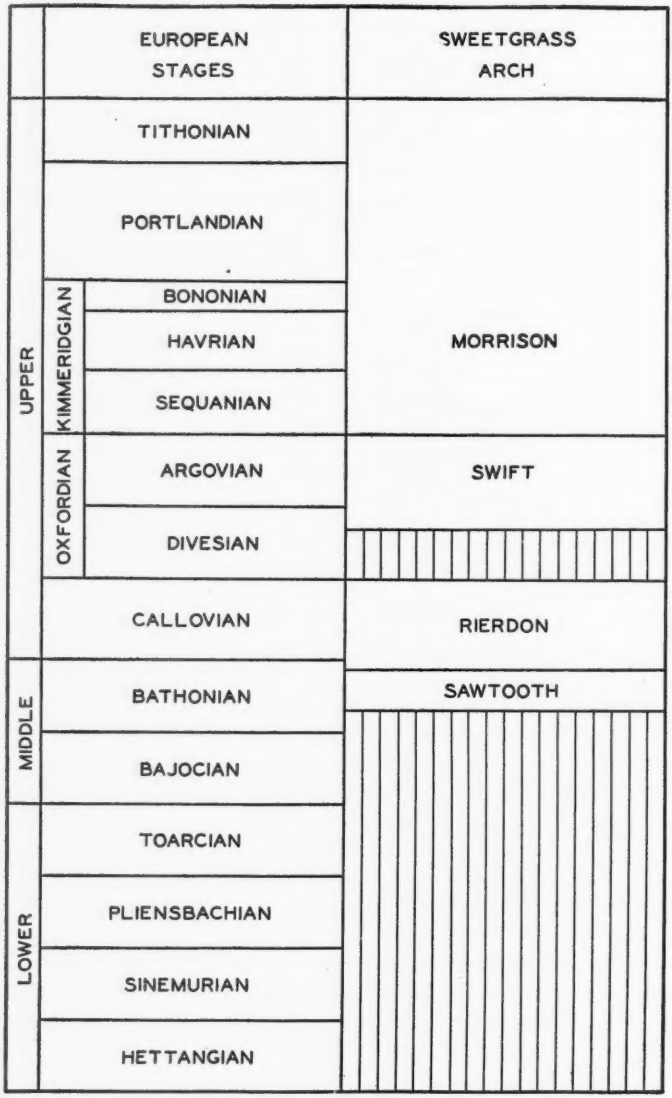

FIG. 1.—Time relations of Ellis group of Sweetgrass arch with standard European stages.

J. H. McCourt and J. E. Hupp, geologists of the Union Oil Company of California, John E. Blixt, geologist of The Texas Company, C. E. Erdmann, regional geologist of the United States Geological Survey, Fred C. Platt, State oil and gas supervisor, E. Byers Emrick, consulting geologist, and M. E. Porter, president of Hannah-Porter Company, kindly allowed the writer to examine large collections of well cuttings. Additional well cuttings were made available by Ralph C. Chamberlain, A. B. Cobb, and F. J. Buscher of Great Falls, R. G. Parrent of Sunburst, Charles N. Wrighter of Kevin, J. C. Gulick of Joplin, George Coffey of Choteau, and Ike W. Taylor of Centralia, Illinois.

J. D. Weir, geologist of The California Standard Company, and F. L. Fournier and S. A. Kerr, geologists of Imperial Oil Limited, furnished sample descriptions of wells drilled on the southern Alberta plains. This information has been taken into consideration in the preparation of the isopach maps.

R. E. Peck, now with the United States Army Air Forces, examined some of the microfossils collected by the writer from continental beds conformably overlying the Swift formation. Although the material was not sufficiently freed from the matrix for specific identification, Peck pointed out its affinities with microfossils of the Morrison formation of other areas.

The writer expresses appreciation and thanks to D. L. Blackstone, Jr., division geologist of The Carter Oil Company, and C. E. Erdmann and R. W. Imlay, for reading and criticizing the manuscript.

STRUCTURAL BACKGROUND AND LOCATIONS OF JURASSIC OUTCROPS

In Montana two large structural features form the Sweetgrass arch.[3] The northern structure is the Kevin-Sunburst dome, about six townships long and six townships wide, with a total closure of 850 feet. The southern structure is known as the South arch. It lies somewhat *en échelon* to the Kevin-Sunburst dome and covers approximately three or four times as much area. The South arch plunges gently northwest away from the Little Belt Mountain uplift, and is terminated on the northwest by one or more normal faults (Pendroy fault zone). Jurassic rocks are at the surface only on the southeastern part of the South arch where they form a narrow belt around the northern flank of the Little Belt Mountains. Good sections can be seen along Belt Creek 8 or 9 miles south of Belt, along Smith River valley in the southern part of T. 16 N., R. 3 E., along the upper part of Porcupine Creek in T. 15 N., Rs. 2 and 3 E., and near the head of Ming Coulee just northeast of Calvert.

Northeast of the Kevin-Sunburst dome are three groups of igneous uplifts

[3] Eugene S. Perry, "The Kevin-Sunburst and Other Oil and Gas Fields of the Sweetgrass Arch," *Montana State Bur. Mines and Met. Mem. 1* (1928).

A. J. Collier, "The Kevin-Sunburst Oil Field and Other Possibilities of Oil and Gas in the Sweetgrass Arch, Montana," *U. S. Geol. Survey Bull. 812-B* (1929), pp. 85–86, Pl. 15.

Thomas B. Romine, "Oil Fields and Structure of Sweetgrass Arch, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (1929), pp. 779–97, Fig. 1.

C. E. Dobbin and C. E. Erdmann, "Structural Contour Map of the Montana Plains," *U. S. Geol. Survey* (1932; revised, 1935).

and plugs known as the East Butte, Middle Butte, and West Butte, and collectively, as the Sweetgrass Hills. Jurassic rocks are exposed in the East and West Buttes. The only complete sections are exposed in East Butte, and the best section is on Sage Creek.

From 50 to 60 miles west of the axis of the Kevin-Sunburst dome and from 10 to 25 miles west of the axis of the South arch is the eastern boundary of the Disturbed Belt. The Disturbed Belt is featured by sharp folds underlain by thrust faults trending in a general north or northwest direction. The belt ranges from 6 to 30 miles in width. Along the western side of the Disturbed Belt south of T. 31 N., Jurassic rocks are exposed at a number of localities but in most places as incomplete sections in which the beds are much crumpled.

The Disturbed Belt is bounded on the west by the Rocky Mountain Front, which is a belt of high-angle thrust faults involving Mesozoic and Paleozoic rocks. The mountains rise abruptly from the edge of the plains as a series of parallel east- and northeast-facing scarps composed largely of massive Paleozoic limestones. Many excellent Jurassic sections are exposed in the strike valleys and along some of the larger streams flowing eastward directly across the strike of the formations. The best sections are in the Sawtooth Range west of the South arch.

HISTORICAL SUMMARY OF PREVIOUS INVESTIGATIONS

The Ellis formation[4] was named for exposures near Fort Ellis, a few miles southeast of Bozeman, in the southwestern part of Montana. There the Ellis[5] consists of a basal unit of shale and siltstone that is poorly exposed, a medial series of limy shale, dense nodular limestone, and oölite, and an upper thick- and thin-bedded slightly glauconitic sandstone containing black-gray micaceous shale partings. The upper unit contains chert and quartzite pebbles at the base, and rests unconformably on the medial limy unit.

The presence of Jurassic rocks in the vicinity of the Sweetgrass arch was shown by Weed[6] in 1892. Along the northern flank of the Little Belt Mountains, Weed noted two lithologic divisions of the Jurassic; a limestone overlain by a sandstone which was commonly conglomeratic. He pointed out that these divisions were characteristic of the Jurassic throughout central Montana. In 1899 Weed[7] assigned the name, Ellis, to the marine Jurassic rocks on the north flank of the Little Belt Mountains, but added nothing new to their description.

[4] A. C. Peale, "The Paleozoic Section in the Vicinity of Three Forks, Montana," *U. S. Geol. Survey Bull. 110* (1893), Pl. 1.
J. P. Iddings and W. H. Weed, "Livingston Atlas Sheet, Description," *U. S. Geol. Survey Geol. Atlas Folio 1* (1894), p. 2.

[5] W. A. Cobban, R. W. Imlay, and John B. Reeside, Jr., "Type Section of Ellis Formation (Jurassic) of Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 4 (1945), pp. 451–53.

[6] W. H. Weed, "Two Montana Coal Fields," *Bull. Geol. Soc. America*, Vol. 3 (1892), p. 309.

[7] W. H. Weed, "Description of the Fort Benton Quadrangle," *U. S. Geol. Survey Geol. Atlas Folio 55* (1899), p. 2.

Red shale and gypsum are now known to be present in the lower part of the Ellis at many localities in central Montana. Until 1905 these beds were regarded as part of the Carboniferous. Rowe[8] collected Jurassic fossils from a limestone overlying a gypsum deposit near Goodman siding on Belt Creek 6 miles south of Armington. He regarded the gypsum as Jurassic, and pointed out the Jurassic age for several other gypsum deposits in Montana.

Fisher[9] described the Ellis of the Great Falls area with considerable more detail than earlier writers. He also drew attention to the unconformity at the base of the Ellis by pointing out that the Ellis rested upon the Madison limestone (Lower Mississippian) in some localities, and upon the "Quadrant" (Big Snowy group, Upper Mississippian) at other localities. Fisher presented two sections, one at the head of Ming Coulee (Sec. 25, T. 17 N., R. 4 E.) and the other near Goodman siding on Belt Creek. From the descriptions of his sections and from the columnar sections shown on his Plate 7, it is obvious that Fisher considered the gypsum deposit near Goodman siding as part of the "Quadrant." However, during the same year Calvert[10] demonstrated the presence of red shale and gypsum in the lower part of the Ellis in central Montana.

Stebinger[11] applied the name, Ellis, to 240 to 310 feet of marine Jurassic dark calcareous shale with a few thin beds of limestone and sandstone exposed along the Disturbed Belt and Rocky Mountain Front west of the Sweetgrass arch. Recently, Deiss[12] described the Ellis of the Sawtooth Range in detail.

In the Sweetgrass Hills Kemp and Billingsley[13] described the Ellis briefly as "about 200 feet of soft green shales, with some impure shaly limestones and calcareous sandstone layers." Later a section on Sage Creek in the East Butte was described in detail by Sanderson[14] and redescribed more recently by Russell and Landes.[15]

With the development of oil and gas fields on the Sweetgrass arch, descriptive names have come into use to designate the productive zones. Sandstone at the

[8] J. P. Rowe, "Montana Gypsum Deposits," *Amer. Geologist*, Vol. 35 (1905) p. 108.

[9] C. A. Fisher, "Geology of the Great Falls Coal Field, Montana," *U. S. Geol. Survey Bull. 356* (1909), p. 28, Pl. 7.

[10] W. R. Calvert, "Geology of the Lewistown Coal Field, Montana," *U. S. Geol. Survey Bull. 390* (1909), pp. 19–21.

[11] Eugene Stebinger, "Oil and Gas Geology of the Birch Creek-Sun River Area, Northwestern Montana," *U. S. Geol. Survey Bull. 691-E* (1918), pp. 155–56.

[12] Charles Deiss, "Stratigraphy and Structure of Southwest Saypo Quadrangle, Montana," *Bull. Geol. Soc. America*, Vol. 54, No. 2 (1943), pp. 231–36.
———, "Structure of Central Part of Sawtooth Range, Montana," *Bull. Geol. Soc. America*, Vol. 54, No. 8 (1943), pp. 1136–40.

[13] James F. Kemp and Paul Billingsley, "Sweet Grass Hills, Montana," *Bull. Geol. Soc. America*, Vol. 32, No. 4 (1921), p. 468.

[14] J. O. G. Sanderson, "An Ellis (Upper Jurassic) Section at East Butte, Sweetgrass Hills, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (1931), pp. 1157–60.

[15] L. S. Russell and R. W. Landes, "Geology of the Southern Alberta Plains," *Canada Geol. Survey Mem. 221* (1940), p. 15.

base of the Ellis is often called "Ellis sand" although that term is more often applied to the porous upper part of the Madison limestone. In the vicinity of the Sweetgrass Hills a sandy, oölitic limestone member in the lower part of the Ellis is known as the "Strode sand." Over the greater part of the Sweetgrass arch the upper part of the Ellis is a flaggy glauconitic sandstone containing abundant partings of black-gray micaceous shale. On the Kevin-Sunburst dome and across the area from Chester to Dupuyer, this sandstone has received the descriptive term, "Ribboned" or "Ribbon" sandstone, a name introduced into northern Montana from southwestern Alberta. Recent writers[16] have been placing the "Ribboned" sandstone (upper member of the Swift formation of this report) in the base of the Lower Cretaceous Kootenai formation and correlating it with the Cut Bank sandstone of the Cut Bank oil and gas field. In the Kevin-Sunburst field the "Ribboned" sandstone is often called the "Stray sand," and in the oil and gas fields around the East Butte of the Sweetgrass Hills, it has been known as the "Baskoo sand" (contraction for basal Kootenai). In the now abandoned Bannatyne oil field the same sandstone was the producing horizon, and was called the "Emrick" or "Bannatyne sand." Inasmuch as the rest of the Ellis (Sawtooth and Rierdon) is absent in the Bannatyne field, the "Emrick sand" has been regarded as a sandstone in the lower part of the Ellis by all previous writers. The names "Emrick" or "Bannatyne" are still used to designate this sandstone over the South arch.

A common interpretation of the limits of the Ellis of the Sweetgrass arch is that it includes all of the beds from the top of the Madison limestone to either the top or base of a widespread yellow bentonitic mudstone. Over much of the Kevin-Sunburst dome the yellow mudstone is a persistent bed underlying the Sunburst sandstone of the Kootenai formation. Elsewhere on the Sweetgrass arch yellow mudstone may or may not occur at the same horizon. In the Kevin-Sunburst field as much as 20 feet of greenish gray clay shale and mudstone of continental origin lies between the yellow marker and the top of the Swift formation. Farther south this unit of continental beds thickens to 40 or 50 feet in the Midway, Pondera, and Bannatyne fields. Recently, Lyons[17] included as much as 220 feet of variegated continental beds in the upper part of the Ellis near Craig.

CONTINENTAL DEPOSITS OVERLYING ELLIS GROUP

Overlying the Ellis group are continental beds of Upper Jurassic and Lower Cretaceous age. The thickness ranges from 348 feet in the Flat Coulee oil field on the north side of the Sweetgrass Hills to about 1,300 feet along the Rocky

[16] Charles E. Erdmann and John R. Schwabrow, "Border-Red Coulee Oil Field, Toole County, Montana, and Alberta, Canada," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol. (1941), p. 292.

John E. Blixt, "Cut Bank Oil and Gas Field, Glacier County, Montana," *ibid.*, pp. 349, 362–64, 369, 371, Figs. 8, 9.

[17] John B. Lyons, "Igneous Rocks of the Northern Big Belt Range, Montana," *Bull. Geol. Soc. America*, Vol. 55, No. 4 (1944), p. 450.

Mountain Front near Craig. These beds are divisible into three major rock units.

The lowest unit is composed chiefly of fine-grained rocks, largely clay shale and mudstone, dense gray limestone, and fine- to very fine-grained gray and brown sandstones. The dominant color of the clay shale and mudstone is greenish gray. The unit is as much as 310 feet thick, and rests conformably upon the Swift formation of the Ellis group. Along the Little Belt Mountains and west to Craig, the top of the unit is either a coal bed or black carbonaceous clay and mudstone. Charophyte oögonia and ostracods from the lower part of the unit show definite Morrison (Jurassic) affinities. The age of the beds must be Kimmeridgian and possibly younger.

The medial unit consists of about 200 feet of beds characterized by red mudstone and whitish sandstones. West of the Kevin-Sunburst dome, and at a few localities along the Rocky Mountain Front, the base of the unit is a coarse black chert sandstone and conglomerate. This bed is known as the Cut Bank sandstone in the Cut Bank-Darling area, and as the Cosmos sandstone in the Border-Red Coulee field. The black chert sandstone is overlain by the Sunburst, zone, which consists of drab-maroon mudstone and white to light gray fine- to coarse-grained lenticular sandstones. Over the Kevin-Sunburst dome and South arch a coarse white to buff sandstone, called Sunburst, forms the base of the medial unit. The sandstone contains much white bentonitic clay cement. It grades upward into white, light gray, light lavender, and light green bentonitic mudstone containing scattered sand grains. The mudstone is commonly mottled bright yellow, salmon, or red. It is overlain by red, red-maroon, or purple mudstone containing numerous odd-shaped dense limestone nodules. The top of the medial unit is composed of thin-bedded to shaly lavender, gray, or greenish gray micaceous sandstone which may contain concentrations of magnetite grains. In the area extending from Great Falls southeast beyond Armington, persistent beds of fresh-water limestone are present near the top of the unit. Fossils from the highest bed include *Unio hamili* McLearn and *Corbula? onestae* McLearn, which occur in the lower part of the Blairmore formation of Alberta, and are considered of Aptian age (Lower Cretaceous) by McLearn.[18]

The highest rock unit consists of dark bluish green, olive-green, olive-drab, purple, and drab-maroon mudstone with highly lenticular beds of greenish gray sandstone. The unit is as much as 800 feet thick, and rests conformably on the magnetite sandstones of the medial unit. Fossils are very rare, poorly preserved, and fragmentary. The age of the beds must be late Aptian or early Albian inasmuch as the basal part of the overlying Colorado shale is Albian in age.[19]

The writer considers the lowest rock unit as Morrison, and the other two as

[18] F. H. McLearn, "Mesozoic Palaeontology of Blairmore Region, Alberta," *Geol. Survey of Canada Mus. Bull. 58* (1929), p. 104.

[19] John B. Reeside, Jr., "Maps Showing Thickness and General Character of the Cretaceous Deposits in the Western Interior of the United States," *U. S. Geol. Survey Prelim. Map. 10*, Oil and Gas Investig. Ser. (1944).

Kootenai. West of the Kevin-Sunburst dome the Kootenai rests unconformably on the Morrison, Swift, and Rierdon formations. An understanding of this unconformity is important not only in the interpretation of the Morrison-Kootenai beds, but also in the distribution and thickness of the Swift formation.

Following the deposition of the Morrison, the Sweetgrass arch was elevated slightly and several low anticlines and shallow synclines were formed. Subsequent erosion removed part of the Jurassic beds from the crests of the anticlines. Erosion was most pronounced on an anticline extending from the Border-Red Coulee field south-southwest through the Cut Bank field. A shallow topographic basin was formed by the removal of the Morrison, part or all of the Swift, and part of the Rierdon along the crest of the anticline and westward for an unknown distance. Into this basin eastward flowing streams deposited black chert sand and gravel at the beginning of Kootenai time while the area east and south of the basin continued to undergo weathering and erosion. It was not until Sunburst time that all of the area received sedimentation. Consequently, the Cut Bank sandstone is the base of the Kootenai locally, whereas the younger Sunburst sandstone or bentonitic mudstone is the base of the formation over the rest of the Sweetgrass arch area.

SAWTOOTH FORMATION

DEFINITION

The Sawtooth is the oldest Jurassic formation of the Sweetgrass arch. Along the Rocky Mountain Front and northeast to the Kevin-Sunburst dome, the formation consists of a basal fine-grained sandstone, a medial dark gray shale containing a few thin dark limestone layers, and an upper highly calcareous siltstone. A Bathonian age is indicated by the fossils.

The formation is named from the Sawtooth Range in which it is well developed and exposed. The section in Rierdon Gulch, described in this report, is considered the type for the formation.

THICKNESS AND DISTRIBUTION

The thickness and distribution of the Sawtooth is shown in Figure 2. The formation is thickest along the Rocky Mountain Front and in a trough extending slightly south of west from the Sweetgrass Hills to the Rocky Mountain Front. The Sawtooth is thinned over the Kevin-Sunburst dome, and is absent over most of the South arch.

At the type section the Sawtooth is 137 feet thick. In the California Company's Government well No. 1 in Sec. 26, T. 27 N., R. 9 W., the Sawtooth is 156 feet thick. The formation thins eastward across the Disturbed Belt to a vanishing edge in the Pendroy-Choteau area.

In the northern part of the Cut Bank field the Sawtooth is as much as 102 feet in thickness. It thins east to as little as 8 feet on the Kevin-Sunburst dome. In the Bears Den field the formation is 185 feet thick.

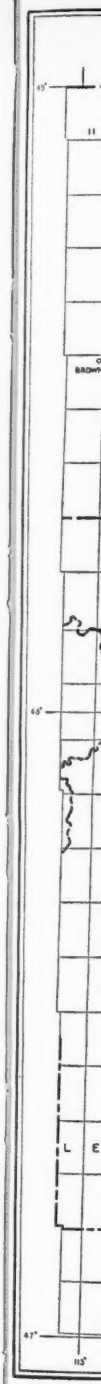

FIG. 2.—Is

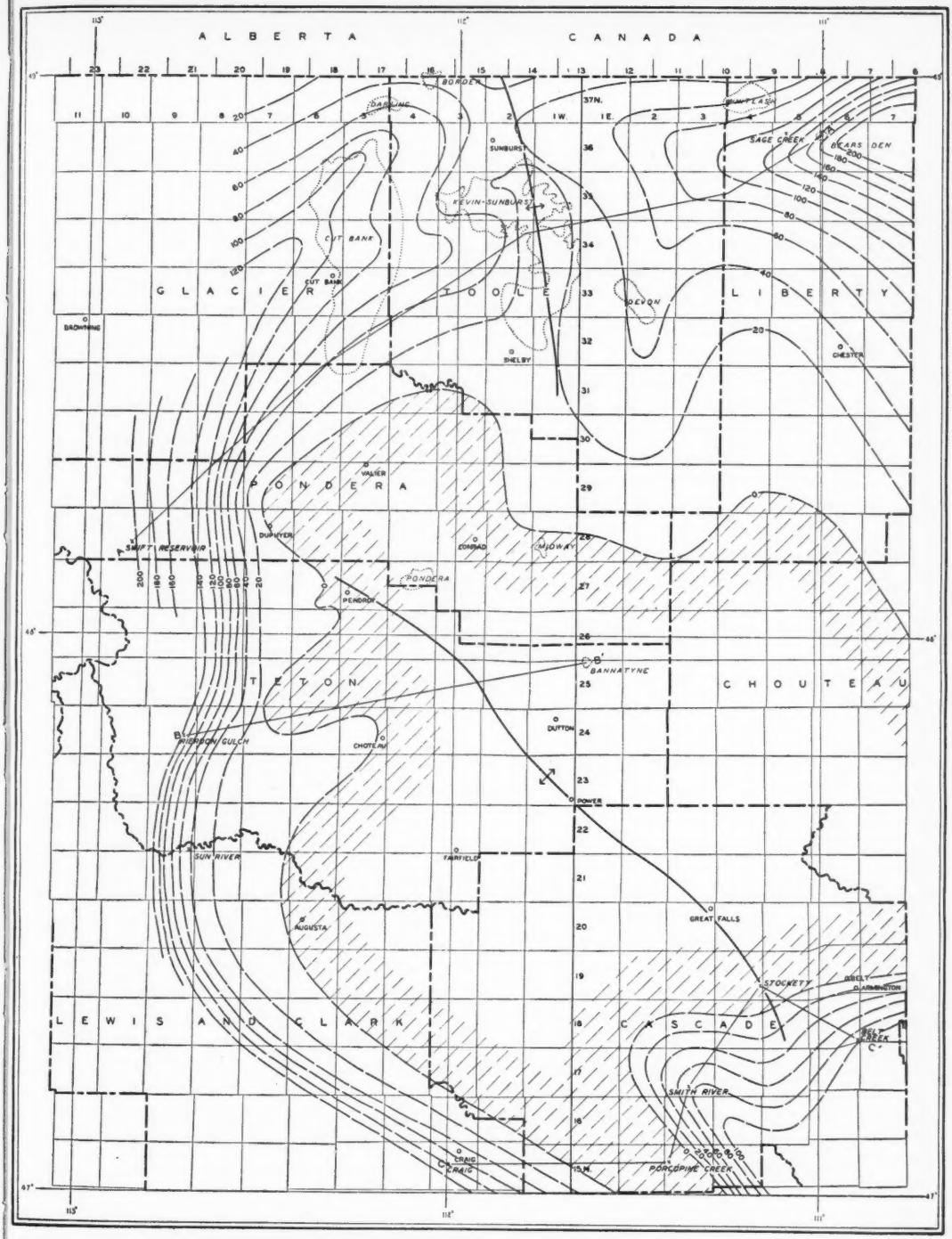

FIG. 2.—Isopach map of Sawtooth formation. Contour interval 20 feet. Shows axes of present South arch and Kevin-Sunburst dome, and boundaries of most of the oil and gas fields. Map scaled in townships.

Near Craig in Sec. 16, T. 15 N., R. 3 W., the Sawtooth is more than 80 feet thick. The formation is absent on Porcupine Creek 26 miles east of Craig. On Belt Creek near Goodman siding 92 feet of siltstone, limestone, and maroon and green shale with minor amounts of gypsum are equivalent to the Sawtooth.

LITHOLOGIC CHARACTER

Rocky Mountain Front.—At the head of Rierdon Gulch in Sec. 23, T. 24 N., R. 9 W., the Sawtooth consists of the following lithologic units: (1) basal sandstone as much as 20 inches in thickness, (2) dark gray shale 83 feet thick, and (3) orange-tan weathering calcareous siltstone 52 feet thick. These units can be recognized along most of the mountain front.

The basal sandstone is composed chiefly of subangular colorless quartz grains. It is light to medium gray, very fine-grained, calcareous, and hard. Ordinarily the sandstone is very finely pyritic. On the weathered surfaces the pyrite is altered to limonite staining the sandstone rusty brown. In short horizontal distances the bedding of the sandstone changes from massive and non-bedded to thin-bedded or even shaly. Ripple-marks are common. Partings of black-gray fissile shale are generally present, and in places the shale component is greater than the sandstone. In Rierdon Gulch lenses of black phosphatic pebbles are present locally. Between the forks of Teton River in the NE. $\frac{1}{4}$ of Sec. 32, T. 25 N., R. 8 W., the base of the Sawtooth is a conglomerate one foot thick composed of quartzite and limestone pebbles and cobbles as much as 8 inches in diameter. The basal sandstone may be thin everywhere along the mountain front. The maximum thickness measured by the writer did not exceed 8 feet. Locally the sandstone is absent.

Overlying the basal sandstone of the Sawtooth is a member composed largely of alternating units of calcareous and non-calcareous shale. The calcareous shale is dark gray, more or less massive, and poorly fissile, breaking into short thick pieces. To this type of shale the writer applies the adjective "chunky." The non-calcareous shale is black gray and fissile with the bedding planes and joint surfaces ordinarily coated with a yellow powder of iron oxide. The lower half of the member contains minor amounts of very fine sandy shale and rarely very fine-grained sandstone and siltstone partings. A few beds of dark gray hard dense limestone occur in the lower part of the member. The limestones are more or less nodular, and less than one foot in thickness. They weather light bluish gray to buff. Lenses of black phosphatic pellets are common in the member. The pellets commonly occur in a shaly limonitic matrix in which water-worn belemnites may be present. In Rierdon Gulch two thin bentonite layers are present in the upper part of the member.

The shale member of the Sawtooth thins south from Rierdon Gulch to 18 feet in the Sun River area. North of Rierdon Gulch the member thickens to 106 feet in the California's Government well No. 1. The member thins in a very short

distance eastward on the west flank of the South arch. Five miles southeast of Rierdon Gulch, the shale member is only 8 feet thick in the Rocky Mountain Oil and Gas Company's Salmond well No. 1 in Sec. 4, T. 23 N., R. 8 W.

The upper member of the Sawtooth is largely light to medium gray siltstone in beds averaging 6 inches to one foot in thickness but as much as 3 feet. The siltstone is highly calcareous and some of the beds could be called silty limestone. The siltstone is composed chiefly of colorless quartz grains and minor amounts of pyrite and glauconite set in a calcareous matrix. The lower part of the member is rather poorly bedded and earthy, contains dark gray shale partings, and is transitional from the underlying shale. The siltstone gradually becomes less earthy toward the top of the unit where a very slight increase in grain size can be seen in places. The grain size approaches that of very fine sand, and some of the upper beds might be termed very fine-grained calcareous sandstone. In some places a thin bentonite can be recognized in the lower part of the member, and locally one is present at the top. Black phosphatic pellets are common in the lower shaly part of the member.

The siltstone member forms a conspicuous bright tan to buff cliff or ridge above the slope of the dark shale member, and below the slope of the gray Rierdon shale. The member thins south of Rierdon Gulch to 23 to 25 feet in the Sun River area. North of Rierdon Gulch it is consistently 50 to 60 feet thick.

Cut Bank area.—The three members of the Sawtooth can be recognized from cuttings of wells drilled to the Paleozoic in and about the Cut Bank oil and gas field. In general the shale and siltstone members thin east across the area toward the Kevin-Sunburst dome.

The basal sandstone is composed almost entirely of colorless quartz grains as it is along the mountain front. The sandstone is light gray, calcareous, and fine- to very fine-grained. Fragments of gray chert pebbles are present in the cuttings from several wells. In the Carter Oil Company's Tribal No. 25 in Sec. 27, T. 36 N., R. 6 W., the base of the sandstone is glauconitic. In the Cut Bank field the sandstone ranges between a few inches and 25 feet in thickness.

The shale member is dark gray to dark greenish gray, noncalcareous to slightly calcareous, and very finely pyritic. It contains black phosphatic pellets and a few thin dark limestone layers. The thickness of the member ranges from 45 feet to less than 10 feet.

Over most of the Cut Bank field the siltstone member is similar to that along the Rocky Mountain Front. However, some well cuttings indicate a higher proportion of dark shale partings in the lower part of the siltstone than is normal to the member along the mountain front. Black phosphatic pellets are present locally in the lower part. In the Carter Oil Company's Tribal No. 25 a thin layer of light gray chert granules occurs at the top of the member. Chert granules and small pebbles are common to the top of the member in many localities east of the Kevin-Sunburst dome, but the occurrence in the Carter well is the only one west

of the dome that was noted by the writer. Thicknesses of the siltstone member range from 52 to 45 feet on the west side of the field, and from 40 to 25 feet on the east side.

Kevin-Sunburst dome.—On the Kevin-Sunburst dome the basal sandstone is generally less than 15 feet thick. It is absent in many wells. Lithologically the sandstone is similar to, if not identical with, that of the Cut Bank field. Cuttings from many wells show the presence of gray chert pebbles and, more rarely, black phosphatic pellets.

The shale member thins east from the Cut Bank field, wedging out high on the west flank of the Kevin-Sunburst dome along a line running roughly from the center of T. 32 N., R. 4 W., to the center of T. 37 N., R. 2 W. The shale is dark gray to black gray, finely pyritic, and more or less non-calcareous. It contains some black phosphatic pellets and thin streaks of siltstone. Bluish gray bentonite can be recognized in some cuttings from the lower part of the member.

The siltstone member thins upon the Kevin-Sunburst dome to less than 25 feet. The shale component increases noticeably in the member as it is traced across the northern part of the area, and on the northeast quarter of the dome, the member can be better described as a silty calcareous shale. White or light gray bentonite is present at or near the top of the member in the northern and eastern parts of the field.

In areas where the lower two members of the Sawtooth are missing, the siltstone rests directly on the Madison limestone, a condition comparable with the northwestern and southern parts of the South arch where the siltstone overlaps the older members and rests upon the Mississippian.

An important lithologic change occurs in the siltstone member on the east flank of the Kevin-Sunburst dome. The shaly facies of the northeast quarter of the dome passes east and northeast into a sandstone and siltstone facies. The sandstone is very fine-grained and occurs as lenses and thin layers in the siltstone. Both the sandstone and siltstone are composed almost entirely of colorless quartz. The proportion of sandstone to siltstone increases eastward. Farther down the east flank of the dome cuttings from some wells show well rounded coarse grains of colorless quartz scattered through the sandstone and siltstone. In the same cuttings parts of the sandstone and siltstone contain patches of light gray sandy limestone with traces of poorly developed oölites.

Sweetgrass Hills.—In the area centering around the East Butte all three members of the Sawtooth are present. In the Ellis section on Sage Creek[20] the Sawtooth consists of the following sequence from oldest to youngest: (1) 30 feet of light gray fine-grained calcareous sandstone, (2) 27 feet of alternating beds of dark gray shale and dark limestone, and (3) 50 feet of light gray fine-grained calcareous sandstone containing a thin layer of small chert pebbles at the top. Farther east in the Bears Den field the sequence is as follows: (1) 3 feet of light

[20] Sanderson, *op. cit.*

bluish green to whitish finely pyritic siltstone, (2) 82 feet of dark gray to medium greenish gray calcareous shale containing hard dense drab limestone layers, and (3) 45 feet of light gray fine- to very fine-grained calcareous sandstone, oölitic sandstone, and sandy oölite.

From the area centering around East Butte, the shale member of the Sawtooth wedges out west toward the Kevin-Sunburst dome, south toward the South arch, and north toward some positive element in southern Alberta. The approximate distribution of the member is in the area enclosed by the 80-foot contour in Figure 2.

The upper member of the Sawtooth is largely sandy oölite and oölitic sandstone. The oölite is very light gray, medium gray, or light brown. Typically, it consists of a very light gray limestone or siltstone matrix containing rounded white, medium gray, or dark brown calcareous oölites 0.1 to 0.5 millimeter in diameter, fine to coarse colorless subrounded to rounded frosted quartz grains, and comminuted pelecypod shells. The proportions of the oölites, sand grains, and shell fragments to the matrix and to one another, are highly variable. The member is slightly porous. In the Whitlash, Flat Coulee, and Bears Den fields the member has produced a little oil, and is known as the "Strode sand."

Ten miles northeast of the Bears Den field the S. G. S. Oil and Gas Company's Smith No. 1 in Sec. 22, T. 37 N., R. 7 E., drilled the following sequence of beds in descending order above massive pink and white limestone of uncertain age: (1) 60 feet of light gray fine-grained calcareous sandstone, light gray to brownish very fine-grained calcareous oölite, light gray shaly calcareous siltstone, and greenish gray limy shale, (2) 55 feet of greenish gray limy shale, light gray siltstone, and light brown limestone, (3) 20 feet of gray to greenish gray calcareous siltstone containing patches of orange-salmon to white very finely crystalline gypsum, (4) 30 feet of maroon mudstone mottled creamy green and containing patches of gypsum and beds of light brown dense dolomite, and (5) 25 feet of creamy dense dolomite containing patches of gypsum and occasional green shale films. The upper 60 feet of beds is undoubtedly the upper member of the Sawtooth. The underlying 130 feet probably should be correlated with the remainder of the Sawtooth.

South arch.—From the Rocky Mountain Front each of the members of the Sawtooth thins eastward to a vanishing edge well down upon the west flank of the South arch. The siltstone member extends the farthest east, successively overlapping the shale and sandstone members.

Along the northern flank of the Little Belt Mountains the Sawtooth shows some interesting and rapid facies changes. At the head of Ming Coulee and along Smith River valley in the southern part of T. 17 N., R. 3 E., the lower two members of the Sawtooth are absent. The upper member is largely massive light gray poorly bedded sandy limestone resting unconformably on Mississippian rocks. Locally parts of the limestone are oölitic. Fine colorless quartz grains are scattered throughout most of the limestone, but in places they are concentrated to the

extent that the rock would be called a calcareous sandstone. Many of the sandy streaks are arranged in cross-beds.

Along Belt Creek 13 miles northeast of Ming Coulee the Ellis section below the Swift sandstone consists of the following units from oldest to youngest: (1) 21 feet of gray calcareous siltstone and silty limestone, (2) 26 feet of maroon and yellowish shale and siltstone containing gypsum and thin beds of oölitic limestone and green shale, (3) 23.5 feet of green shale and thin limestones, and (4) 23 feet of more or less thin-bedded gray to yellowish sandy limestone. All of this section is probably correlative with the Sawtooth.

Reddish and yellowish shale and siltstone containing gypsum is common in the lower part of the Ellis in central Montana. Imlay[21] has pointed out that these beds are correlative by general lithologic features and fossils with the Gypsum Springs formation of Wyoming. The name, Gypsum Springs, is more applicable than Sawtooth for the lower part of the Ellis on Belt Creek and in the S. G. S. Oil and Gas Company's Smith well No. 1 east of the Sweetgrass Hills.

FOSSILS AND AGE

The Sawtooth contains many fossils. Imlay[22] lists the following pelecypods from the basal sandstone of the Sawtooth at Swift Reservoir: *Oxytoma blairmorensis* McLearn, *Trigonia* cf. *T. trafalgarensis* Warren, *Eumicrotis* n. sp. aff. *E. ferniensis* (McLearn), and *Astarte* (*Coelastarte*) n. sp.

Fossils are abundant in some parts of the shale member. Fossils collected by Deiss[23] from this member in Rierdon Gulch and identified by Imlay[24] are *Ostrea* sp., *Nucula* n. sp., *Trigonia montanaensis* Meek, *Astarte meeki* Stanton, *Astarte* cf. *A. packardi* Meek, *Tancredia* cf. *T. inornata* Meek, *Tancredia* sp., *Gryphaea* sp. juv., cf. *G. impressimarginata* McLearn, *Volsella rosii* (McLearn), *Lithophaga?* n. sp., *Protocardia schucherti* McLearn, *Pleuromya obtusiprorata* McLearn, *Lucina* sp., *Dentalium* sp., *Procerithium* (*Rhabdocolpus*) n. sp., and *Pachyteuthis* sp. From the lower part of the shale member at Swift Reservoir Imlay collected a poorly preserved ammonite which he has provisionally assigned to *Cranocephalites*.

The siltstone member is highly fossiliferous. Along the Rocky Mountain Front the most abundant forms are species of *Camptonectes*, *Pleuromya*, and *Gryphaea*. Fossils collected by Deiss[25] from this member in Rierdon Gulch and identified by Imlay[26] are *Ostrea strigilecula* White, *Arctica?* cf. *A. iddingsi* (Stanton), *Astarte meeki* Stanton, *Astarte* aff. *A. packardi* Meek, *Eumicrotis ferniensis*

[21] Ralph W. Imlay, "Occurrence of Middle Jurassic Rocks in Western Interior of United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 7 (July, 1945), pp. 1023–25.

[22] Imlay, *op. cit.*, p. 1024.

[23] Charles Deiss, "Structure of Central Part of Sawtooth Range, Montana," *Bull. Geol. Soc. America*, Vol. 54, No. 8 (1943), p. 1138.

[24] Imlay, *op. cit.*, p. 1024.

[25] Deiss, *op. cit.*, pp. 1137–38.

[26] Imlay, *op. cit.*, p. 1024.

McLearn, *Camptonectes pertenuistriatus* Hall and Whitfield, *Camptonectes platessiformis* White, *Trigonia montanaensis* Meek, *Pleuromya obtusiprorata* McLearn, *Pholadomya kingi* (Meek), *Pinna kingi* Meek, *Protocardia schucherti* McLearn, *Grammatodon* n. sp., *Arctocephalites* sp. juv., *Pachyteuthis* sp., *Pentacrinus asteriscus* Meek and Hayden, and a naticoid gastropod. *Gryphaea impressimarginata* McLearn is common in the member at Rierdon Gulch and Swift Reservoir. From the siltstone member in Rierdon Gulch Imlay collected the ammonites, *Arctocephalites* and *Arcticoceras*.

Two faunal zones are recognized by Imlay[27] in the Sawtooth along the Rocky Mountain Front. The oldest is the *Cranocephalites* zone, which occurs in the basal sandstone and in the shale member of the Sawtooth. The youngest zone is characterized by *Arctocephalites*, which occurs in the siltstone member. Both zones are considered upper Bathonian in age.

RIERDON FORMATION

DEFINITION

The name, Rierdon, is herein applied to the group of alternating gray limy shales and limestones overlying the upper sandy beds of the Sawtooth and disconformably underlying the dark gray micaceous shale and sandstone of the Swift formation. The Rierdon is defined solely on the basis of its lithologic character. At the type locality in Rierdon Gulch in Sec. 23, T. 24 N., R. 9 W., the lower part of the formation is of upper Bathonian age and the remainder lower Callovian. However, the age range of the formation varies. Its basal beds are younger on the flanks of the South arch than along the Rocky Mountain Front. The age range of the upper part of the formation is varied because of the effects of early Divesian erosion. Beds of middle and upper Callovian age are present in the Rierdon in the Sweetgrass Hills.

THICKNESS AND DISTRIBUTION

A comparison of the isopach map of the Rierdon (Fig. 3) with the Sawtooth (Fig. 2) shows that the thicknesses and distribution of the formations are somewhat similar. Most of the South arch continued through the Callovian stage as a positive element. Likewise, the Kevin-Sunburst dome remained high enough to influence sedimentation. The thickening of the Rierdon into a trough trending east-northeast away from the Kevin-Sunburst dome is comparable with a similar thickening of the Sawtooth in the same area. A pronounced thinning of the Rierdon occurs just southeast of the Devon gas field in an area trending northeast. In the Cut Bank field field the Rierdon has been reduced by pre-Kootenai erosion to probably less than half its original thickness in many places.

The Rierdon is 137 feet thick at the type locality. It thickens in a general westerly direction to more than 200 feet in the Badger Creek area in Sec. 3, T. 29

[27] Imlay, *op. cit.*, p. 1022.

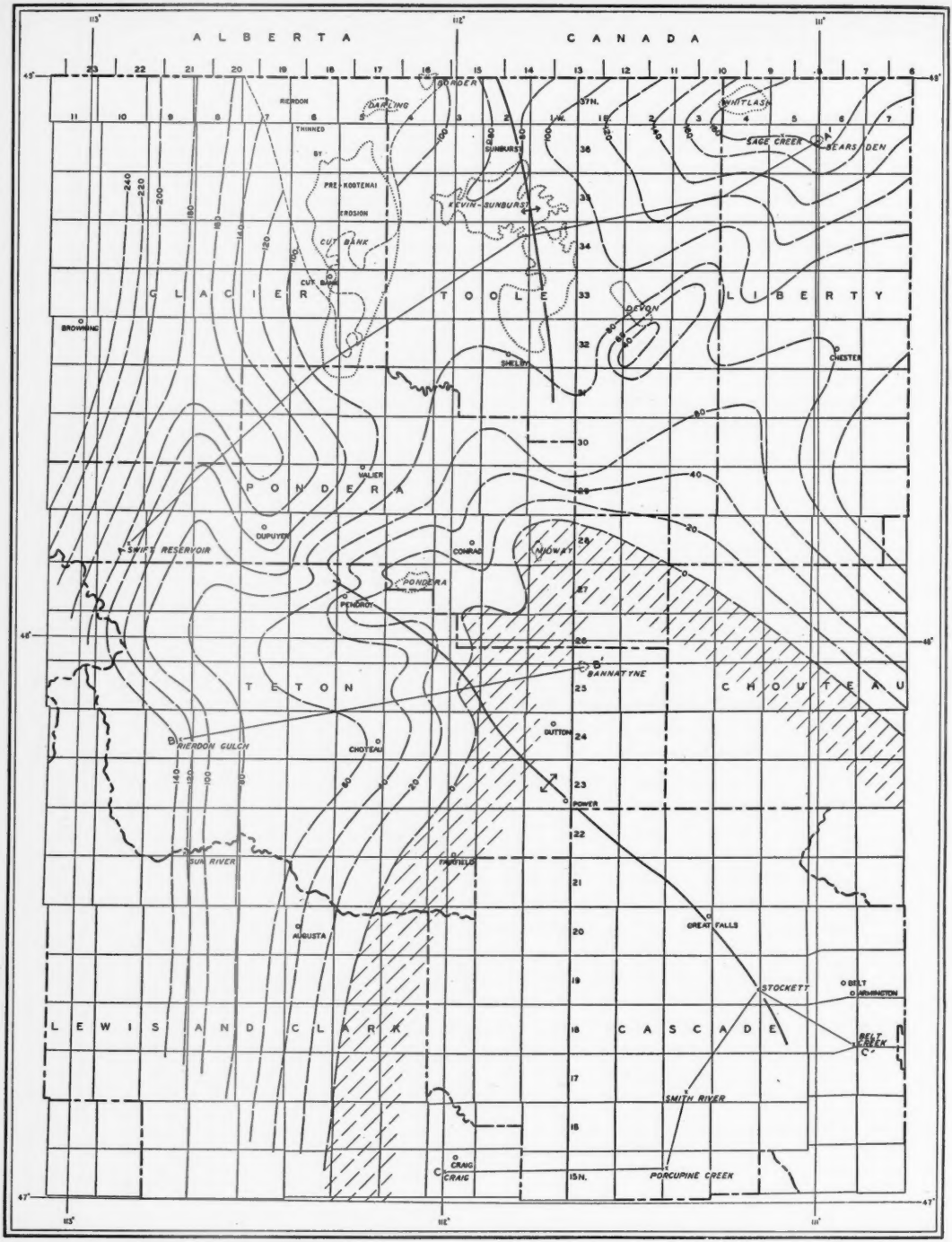

FIG. 3.—Isopach map of Rierdon formation. Contour interval 20 feet. Shows axes of present South arch and Kevin-Sunburst dome, and boundaries of most of the oil and gas fields. Map scaled in townships.

N., R. 11 W. The formation is 65 to 90 feet thick in the Cut Bank field, and 72 to 91 feet in the Kevin-Sunburst. At the section on Sage Creek in Sec. 8, T. 36 N., R. 5 E., the thickness is about 180 feet. In the Bears Den field the Rierdon is 185 feet thick. In the Pondera field the thickness ranges from 19 feet on the west side to 11 feet on the east. The formation is absent in the Midway and Bannatyne fields.

LITHOLOGIC CHARACTER

Rocky Mountain Front.—At the type locality the Rierdon consists of the following units from oldest to youngest: (1) 20.5 feet of medium gray chunky limy shale containing a few dense gray nodular limestones, (2) 33.5 feet of dark medium gray fissile calcareous to almost non-calcareous shale containing thin beds of gray dense nodular limestone, (3) 43.5 feet of medium gray chunky limy shale containing a few thin beds of limestone in the lower part, and (4) 39 feet of alternating 4- to 6-inch limestone layers and thicker beds of medium gray chunky limy shale. Twenty-four feet above the base is a 3-foot chunky limy shale containing two medium gray dense nodular limestone beds each overlain by one-inch shaly limonitic layers containing large water-worn *Gryphaea*. These limonitic layers apparently represent hiatuses. The large waterworn *Gryphaea* is probably *Gryphaea impressimarginata* McLearn, which is abundant in the siltstone member of the Sawtooth and in the lower 20 feet of the Rierdon. The fossil is apparently confined to the Middle Jurassic.[28] As the fossils from the overlying part of the Rierdon are Callovian in age, the hiatuses described in the preceding paragraph appear to mark the Bathonian-Callovian boundary.

The limestone beds in the Rierdon are lithologically very similar to the shale. On fresh exposure the limestones are dense and more or less of the same color as the shale, although the less argillaceous limestones are slightly lighter than the shale. Most of the limestones have a nodular appearance, and grade upward and downward into the shale.

Most of the shale of the Rierdon is very limy, chunky, somewhat nodular, and has a slight olive-greenish cast. On fresh exposure little or no bedding can be observed, and the rock closely resembles the limestones. Upon weathering the shale ordinarily breaks into splintery fragments. In the lower part of the Rierdon (20.5 to 64 feet above the base in the type locality) the shale is dark, fissile, and much less calcareous than the rest of the formation. This dark unit divides the formation into three shale members: (1) a basal medium gray limy chunky shale with nodular limestones, (2) a medial dark gray fissile slightly calcareous or non-calcareous shale with nodular limestones, and (3) an upper medium gray limy chunky shale with nodular limestones. These divisions are useful in subsurface studies on the Sweetgrass arch.

White barite concretions occur in the middle third of the formation. Some of these attain diameters of as much as 10 inches.

[28] Ralph W. Imlay, personal communication.

South of Rierdon Gulch in the Sun River area thin partings of siltstone and very fine sandstone are present in the lower part of the Rierdon. Similar conditions exist northwest of Rierdon Gulch in the Badger Creek area.

The Rierdon typically weathers to a steep slope. The outcrop is conspicuously banded by the harder limestone layers and beds of buttress-forming shale. The limestones weather bluish gray to buff.

Cut Bank and Kevin-Sunburst areas.—On the Kevin-Sunburst dome and in the Cut Bank area, the Rierdon is composed of the three lithologic members. The basal 10 to 20 feet consists of medium gray chunky limy shale containing gray dense limestones. It is overlain by 15 to 25 feet of dark fissile finely pyritic noncalcareous to slightly calcareous shale containing thin limestone layers. The top member consists of 30 to 50 feet of medium gray limy chunky shale containing numerous thin limestone beds. Both the shale and limestone of the upper member contain some scattered glauconite grains as much as 1.0 millimeter in diameter but ordinarily ranging between 0.25 and 0.5 millimeter. All the beds have an olive-greenish cast which seems to vary in intensity in different localities.

Sweetgrass Hills.—Each of the members of the Rierdon thickens east away from the Kevin-Sunburst dome. In the Bears Den field the upper limy member is about 95 feet thick, the middle dark fissile member is about 50 feet, and the lower limy member is 40 feet. The lithology is similar to that of the Kevin-Sunburst dome with the exception that the lower member contains a few silty to very finely sandy partings.

South Arch.—From the Rocky Mountain Front the Rierdon thins eastward on the South arch. Well cuttings in the Pendroy-Choteau area show the dark fissile pyritic shale member resting directly on Mississippian limestone. Apparently the basal limy member (Bathonian) of the Rierdon Gulch area thins eastward to a vanishing edge somewhere along the Disturbed Belt. The dark fissile shale member and the overlying chunky limy shales are much thinner in the Pendroy-Choteau area than along the mountain front, which would suggest that the Rierdon is absent over the greater part of the South arch because of non-deposition rather than a result of early Divesian erosion.

FOSSILS AND AGE

Fossils are abundant in the Rierdon, particularly in the uppermost part where some layers are crowded with *Gryphaea nebrascensis* Meek and Hayden. Imlay[29] recognizes three faunal zones in the beds here assigned to the Rierdon. The lowest zone is characterized by *Arctocephalites* of upper Bathonian age, the middle zone by *Cadoceras* of lower Callovian age, and the highest zone by *Kepplerites* of middle and upper Callovian.

In Rierdon Gulch, fossils collected by Deiss[30] from the lower 38 feet of the

[29] Imlay, *op. cit.*, p. 1022–23.

[30] Deiss, *op. cit.*, p. 1137.

Rierdon, are identified by Imlay[31] as *Gryphaea impressimarginata* McLearn, *Corbula munda* McLearn, *Astarte meeki* Stanton, *Pleuromya obtusiprorata* McLearn, *Trigonia montanaensis* Meek, *Grammatodon* n. sp., and *Camptonectes* sp. The writer found an ammonite, identified by Imlay as an *Arctocephalites*, 20 feet above the base of the formation at the type locality.

Fossils collected by Deiss[32] from the upper part of the formation in Rierdon Gulch are identified by Imlay[33] as *Gryphaea nebrascensis* Meek and Hayden, *Camptonectes pertenuistriatus* Hall and Whitfield, and *Pachyteuthis* sp. In addition Imlay collected large specimens of the ammonite, *Cadoceras*.

The highest beds of the Rierdon in the East Butte of the Sweetgrass Hills contain *Kepplerites* and *Cosmoceras*.[34]

SWIFT FORMATION

DEFINITION

Along the Rocky Mountain Front and over the Kevin-Sunburst dome, the youngest marine Jurassic rocks consist of dark gray non-calcareous shale overlain by fine-grained glauconitic flaggy sandstone. On the South arch and along the northern flank of the Little Belt Mountains, the youngest marine Jurassic rocks consist of a massive fine-grained sandstone overlying a basal conglomerate, or a massive flaggy sandstone containing abundant dark non-calcareous shale partings. This sandstone or sandstone and shale sequence is herein named the Swift formation, taking its name from Swift Reservoir on Birch Creek where the beds are well exposed and easily accessible on the north shore in the NE. $\frac{1}{4}$ of Sec. 27, T. 28 N., R. 10 W.

THICKNESS AND DISTRIBUTION

The Swift formation was deposited over the entire Sweetgrass arch. Pre-Kootenai erosion later removed the formation from most of the Cut Bank area and from a small area west of the Whitlash dome. South of T. 28 N. the Swift is conformably overlain by fine-grained continental deposits equivalent to the lower part of the Morrison formation of areas farther south. North of T. 28 N. the Swift is overlain conformably by the Morrison in some areas, but in other localities the Swift is overlain unconformably by the Cut Bank or Sunburst sandstones of the basal Kootenai formation. Thus the isopach map of the Swift (Fig. 4) shows the original thicknesses of the formation over most of the area, but in the northern part the thicknesses indicated are commonly of erosional remnants.

The Swift is 135 feet thick at the type locality. On the Kevin-Sunburst dome original thicknesses range from 100 to 120 feet. In the Bears Den field the thickness is about 90 feet. The Swift is 166 feet thick in the Pondera field, 155 feet in

[31] Imlay, *op. cit.*, p. 1024.

[32] Deiss, *op. cit.*, p. 1137.

[33] Imlay, *op. cit.*, p. 1024.

[34] Personal communication from Ralph W. Imlay.

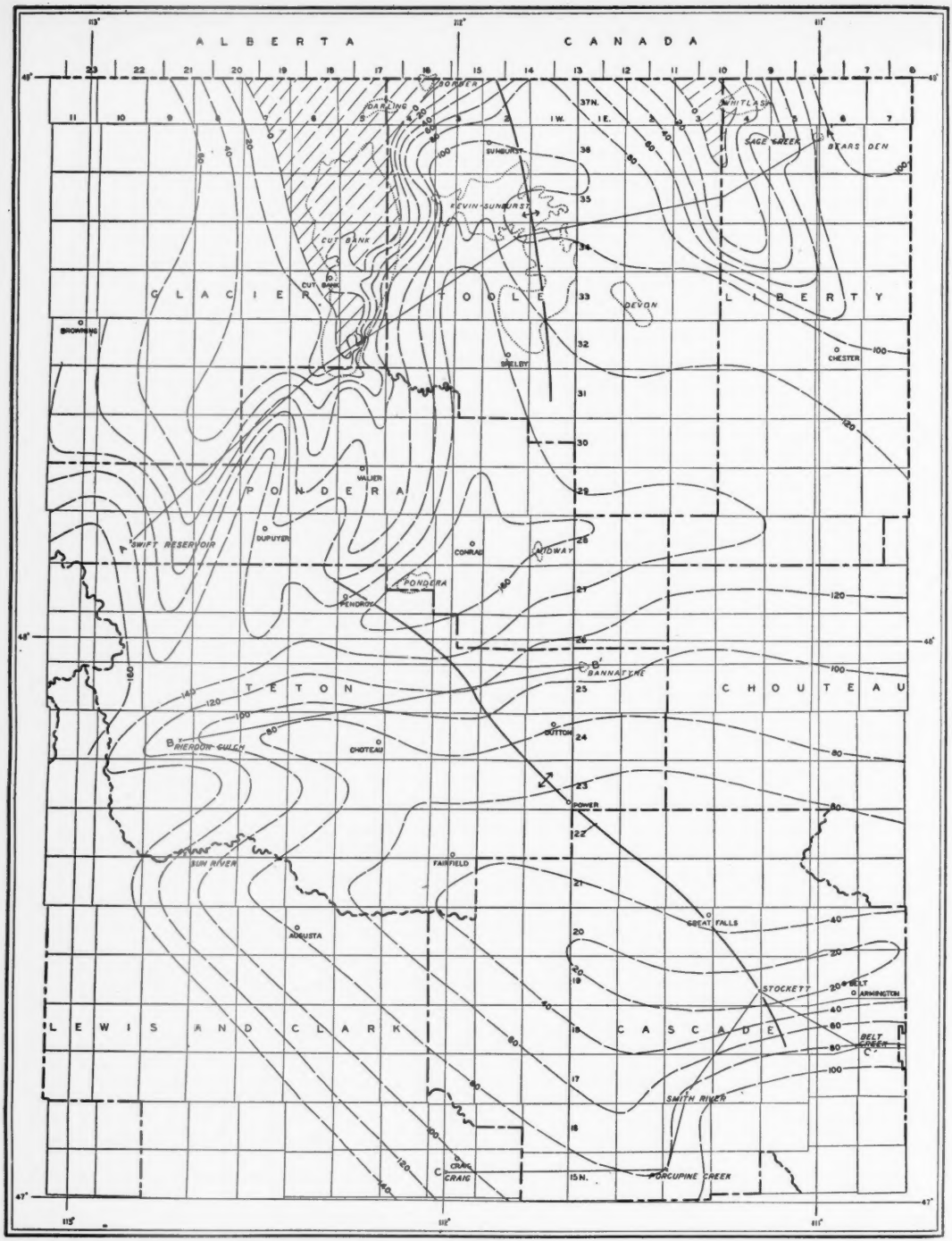

FIG. 4.—Isopach map of Swift formation. Contour interval 20 feet. Shows axes of present South arch and Kevin-Sunburst dome and boundaries of most of the oil and gas fields. Map scaled in townships.

the Midway field, and a little more than 100 feet in the Bannatyne field. The original thickness of the formation at Stockett in Sec. 36, T. 19 N., R. 4 E., is 10 feet. South of Stockett along the northern flank of the Little Belt Mountains, the formation is 79 to 89 feet thick.

LITHOLOGIC CHARACTER

Rocky Mountain Front.—At the type locality the Swift consists of two members. The lower member is a dark gray non-calcareous shale 54.5 feet thick. The upper member is a flaggy ripple-marked sandstone 80 feet thick containing abundant black-gray fissile shale partings.

The shale of the lower member of the Swift at the type locality is very finely micaceous, and contains some pyrite and very hard streaks of dark siltstone. Large hard bright rusty brown-weathering calcareous concretions and clay ironstones occur throughout the member. The concretions are dark gray on fresh exposure. The basal few inches of the member is highly glauconitic and contain water-worn belemnites and rarely black chert pebbles as much as $\frac{1}{2}$ inch in diameter.

The sandstone of the upper member of the Swift is composed chiefly of angular to subangular colorless quartz with some subangular gray and black chert and a little glauconite. The grains are largely fine, but some medium and coarse grains are present in the lower part. Many of the quartz grains occur as small anhedral crystals. The sandstone occurs as hard ripple-marked lenses containing numerous burrows and trails. Bluish weathering, black-gray micaceous shale films are present in and around the sandstone lenses. The mica in the shale films is a white variety. Brown or black prints of driftwood, many occurring as thin coaly lenses, are common in the member. The base of the member is a lenticular bed of dark gray conglomerate as much as 7 inches thick containing small black chert pebbles, belemnites, fish teeth, comminuted pelecypod shells, and glauconite.

The lithologic character of the Swift formation at the type locality persists along the mountain front from the south boundary of Glacier National Park southeast almost to Sun River. At many localities small black chert pebbles are present in the basal part of the sandstone member as well as in the base of the shale member. In Rierdon Gulch a very hard massive, lenticular bed of fine- to very fine-grained sandstone forms the base of the sandstone member. This bed is as much as 22 feet in thickness, but in short distances it is absent. The thickening and thinning of the bed takes place from the top downward. This form of sandstone was not observed in any of the other sections examined by the writer.

From Sun River southeast along the mountain front, the Swift becomes increasingly sandy. The shale member contains fine-grained ripple-marked sandstone lenses with bluish-weathering shale films. Sandy layers at and near the base are highly glauconitic and contain the usual water-worn belemnites. The bright rusty brown-weathering calcareous concretions and clay ironstones so characteristic of the lower member north of Sun River are not well developed

at Sun River, and are absent south of T. 20 N. A thin conglomerate forms the base of the formation near Craig. The pebbles and cobbles consist of well rounded tan quartzite and dark chert as much as 7 inches in diameter, and smaller pebbles of chert, quartzite, and limestone. The sandstone member of the Swift contains less shale than in areas north of Sun River. The sandstone is fine-grained, thin-bedded, and gently cross-bedded. It weathers gray to buff in the Sun River area, and yellowish near Craig.

Along the Rocky Mountain Front the sandstone member of the Swift crops out as a prominent hogback. The bedding planes and joint surfaces are usually stained dark rusty brown by iron oxide. Near Craig some joint surfaces are coated with a dark desert varnish displaying many colors.

Kevin-Sunburst dome.—Well cuttings and cores from the Kevin-Sunburst field show the Swift to be similar if not identical with the formation along the Rocky Mountain Front north of Sun River. An examination of the cuttings from 20 wells in the field shows that the shale member ranges between 15 and 43 feet in thickness, averaging 25 feet, and the sandstone member ranges between 46 and 100 feet, averaging 78 feet.

In many of the wells the sandstone in the upper 10 to 15 feet of the Swift is very light gray to whitish and contains medium to light gray micaceous shale partings. This light sandstone may possibly be a facies of the Sunburst zone, but from the "ribboned" structure and the presence of glauconite (?) grains, the writer regards the sandstone as the upper part of the Swift.

Cut Bank area.—The Swift is absent over the greater part of the Cut Bank area (Fig. 4). The coarse Cut Bank sandstone at the base of the Kootenai lies unconformably upon the Rierdon in the Border-Red Coulee and Darling fields, and over most of the Cut Bank field. Around the town of Cut Bank and eastward for several miles, the Cut Bank sandstone rests on the basal glauconitic shale of the Swift. Farther east along parts of the eastern edge of the field, the Cut Bank sandstone overlaps the sandstone member of the Swift. Wildcat tests west and southwest of the field show the Swift sandstone member either thinned or removed by pre-Kootenai erosion.

The sandstone member of the Swift has been called the "Ribboned" sandstone and correlated with the Cut Bank sandstone largely because of the following reasons:[35] (1) the sandstones contain black chert which is most abundant toward the base, (2) the sandstones rest sharply on shale, (3) the total thicknesses of the sandstones are approximately the same, and (4) the sandstones appear to occupy the same stratigraphic position. It is not difficult to see why the two sandstones have been correlated because of stratigraphic position in the Cut Bank field inasmuch as the Cut Bank sandstone occupies a shallow basin eroded out of the Swift and Rierdon formations. An important factor not taken into account by earlier writers is that at one locality or another the Cut Bank sandstone rests

[35] Blixt, *op. cit*, pp 363–64, 369, 371.

unconformably on continental beds, both members of the Swift, and on the Rierdon shales and limestones, whereas the "Ribboned" sandstone everywhere overlies a black-gray non-calcareous shale (shale member of Swift) in the area of Cut Bank development. Two important lithologic differences are: (1) the Swift sandstone is glauconitic; the Cut Bank is not glauconitic, and (2) the Swift sandstone contains abundant thin hard black-gray micaceous shale partings, whereas shale partings in the Cut Bank are much less common, and are lighter gray, softer, and less micaceous.

Sweetgrass Hills.—The Swift formation is much thinned and locally absent in an area covering approximately Ts. 34–37 N., Rs. 3–4 E. This is due to pre-Sunburst erosion, and is comparable to the condition in the Cut Bank field. Where all or most of the Swift is present, its lithologic features are similar to those in the Kevin-Sunburst field. In the section on Sage Creek in Sec. 8, T. 36 N., R. 5 E., most of the Swift formation has been omitted by faulting. However, the Swift is well exposed about a mile farther up Sage Creek.

South arch.—The Swift attains its thickest development in the area from Pendroy east through the Midway field. The shale member is as much as 95 feet in thickness in the Pondera field, and 90 feet in thickness in the Carter Oil Company's Warwick test No. 1, 4 miles north of the field in Sec. 14, T. 28 N., R. 4 W. In the Pendroy-Midway area the sandstone member ranges from 60 to 90 feet in thickness.

The glauconitic zone at the base of the formation which is continuous over the Kevin-Sunburst dome and along the Rocky Mountain Front, is not developed over most of the South arch. However, chert pebbles and fragments of belemnites can be seen in cuttings from some of the wells in the Pendroy-Midway area. Well cuttings also show the presence of clay ironstones in the shale member in the same area.

Southeast from the Pendroy-Midway area toward the Bannatyne field, the shale member becomes sandy as it does southeast of Sun River along the mountain front. In most of the wells the two members of the Swift can not be separated with certainty. In general, the lower part of the Swift contains more shale than the upper part.

In the Bannatyne field where the Swift was the producing formation, it consists of fine- to coarse-grained sandstone becoming conglomeratic toward the base. The sandstone is composed chiefly of angular to subangular colorless quartz, subangular black and gray chert, some pyrite, and very little glauconite. The proportion of black chert increases toward the base where the sandstone is very coarse-grained to pebbly, pyritic, and almost black. Black-gray micaceous shale films occur throughout most of the beds.

From the Bannatyne field south to the outcrop along the northern flank of the Little Belt Mountains, the Swift consists of thin-bedded, fine-grained sandstone which is usually coarse or pebbly at or near the base. In the Chamberlain's Heldman well No. 1 in Sec. 6, T. 19 N., R. 2 W., the lower part of the formation con-

tains large white quartz or quartzite pebbles. This is an interesting occurrence inasmuch as most of the pebbles from well cuttings farther north are composed of dark chert. At the outcrop near Craig and eastward along the northern flank of the Little Belt Mountains, the pebbles in the basal part of the Swift are dominantly light gray or light tan quartzite.

Along the northern flank of the Little Belt Mountains the Swift consists of massive thin-bedded sandstone forming prominent yellowish tan cliffs. The base of the sandstone is generally a conglomerate of variable thickness. Some of the quartzite cobbles are as much as 7 inches in diameter. In most of the sections examined by the writer the basal conglomerate passes within a short distance upward into fine- or even very fine-grained sandstone containing micaceous shale films along ripple-marked bedding surfaces. In places, lenses of conglomerate are present higher in the sandstone, and along Smith River some conglomerate streaks are present at the top. Shale partings are most abundant in the lower part of the sandstone just above the basal conglomerate.

FOSSILS AND AGE

The lower member of the Swift contains abundant water-worn belemnites in its base along the Rocky Mountain Front. Some belemnites and more rarely pelecypods occur higher in the shale. East of the Sweetgrass arch, on the east side of the Bearpaw Mountains, Imlay collected *Quenstediceras* from the lower part of the shale member and *Cardioceras* from the upper part. Regarding these fossils Imlay[36] says: "The upper member of the Swift formation is probably Argovian on the basis of stratigraphic position. The lower member is of Divesian age in its lower beds that contain *Quenstediceras*, but its upper beds that contain *Cardioceras* may be either Divesian or Argovian."

The upper member of the Swift contains wood prints and rarely oyster shells and belemnites. In central Montana and at the type locality of the Ellis, the upper member of the Swift contains abundant oyster shells and a few other fossils indicating an Upper Jurassic age.

GEOLOGIC HISTORY

At the beginning of the upper Bathonian the Sweetgrass arch was a broad low uplift that extended from the Little Belt Mountain area north into Canada. The arch was constricted over the Kevin-Sunburst dome to a width of about 15 or 20 miles by a prominent trough trending west from the Sweetgrass Hills to the Kevin-Sunburst dome and by a trough trending northeast from the Cordilleran area. Upon the southeastern part of the arch an embayment extended as far west as Belt Creek. Of the area shown in Figure 2 approximately 9,500 square miles are not covered by the basal sandstone and the shale member of the Sawtooth.

[36] Personal communication.

The basal sandstone of the Sawtooth is a transgressive deposit which probably varies slightly in age from one locality to another. The Sweetgrass arch must have been very low inasmuch as the grain size of the basal sandstone is fine to very fine.

As the marine waters transgressed upon the Sweetgrass arch, dark shale was deposited over the basal sandstone on the west side of the arch, and dark shale and limestone were formed in the Sweetgrass trough. The gypsiferous beds drilled in the S. G. S. Oil and Gas Company's Smith well No. 1 in Sec. 22, T. 37 N., R. 7 E., were probably formed close to the northern shore of the trough. In the shallow Belt Creek embayment redbeds and gypsum were also deposited.

Of the area shown in Figure 2 about 5,400 square miles are not covered by the siltstone member of the Sawtooth. This indicates a considerable decrease in the size of the Sweetgrass arch by the late Bathonian. The arch became an island by the joining of the two northern troughs across the Kevin-Sunburst dome, and by the westward extension of the Belt Creek embayment into the Cordilleran area. Marine waters from the Sweetgrass Hills trough also spread south and southwest at least 30 miles. The axis of the late Bathonian island can be superimposed almost upon the present axis of the South arch (Fig. 2).

The upper part of the Sawtooth is silty or sandy everywhere. In the Belt Creek trough the massive poorly bedded sandy limestones display cross-bedding indicating agitated shallow-water deposition. West of the South arch the member is well bedded and was probably deposited in quiet shallow water. In the Sweetgrass Hills trough the top of the member is coarse-grained and pebbly. The pebbles may have come from some uplift farther east, or possibly from chert in the Madison limestone of the northeastern part of the South arch. Volcanism during the upper Bathonian produced several thin bentonite layers in the middle and upper parts of the Sawtooth.

During the Callovian stage marine waters transgressed across all the northwestern part of the South arch. The absence of the Rierdon in the Belt Creek trough suggests that the South arch was slightly tilted toward the northwest, whereas the southeast end was lifted slightly above sea-level. However, early Divesian erosion removed some of the Sawtooth from the southern part of the South arch, and if the Rierdon had been deposited there, the record may now be lost.

The Sweetgrass Hills trough continued to be a prominent feature throughout the Callovian. The Kevin-Sunburst dome remained high although submerged. The size of the South arch decreased during the Callovian to an area of about 4,700 square miles.

The rather uniform character of the Rierdon limestones and shales indicates quiet-water deposition. The general lack of clastics suggests that the South arch must have been almost at sea-level.

At the close of the Callovian, marine waters retreated from the area. The Sawtooth limestones in the Belt Creek trough were eroded considerably, and part

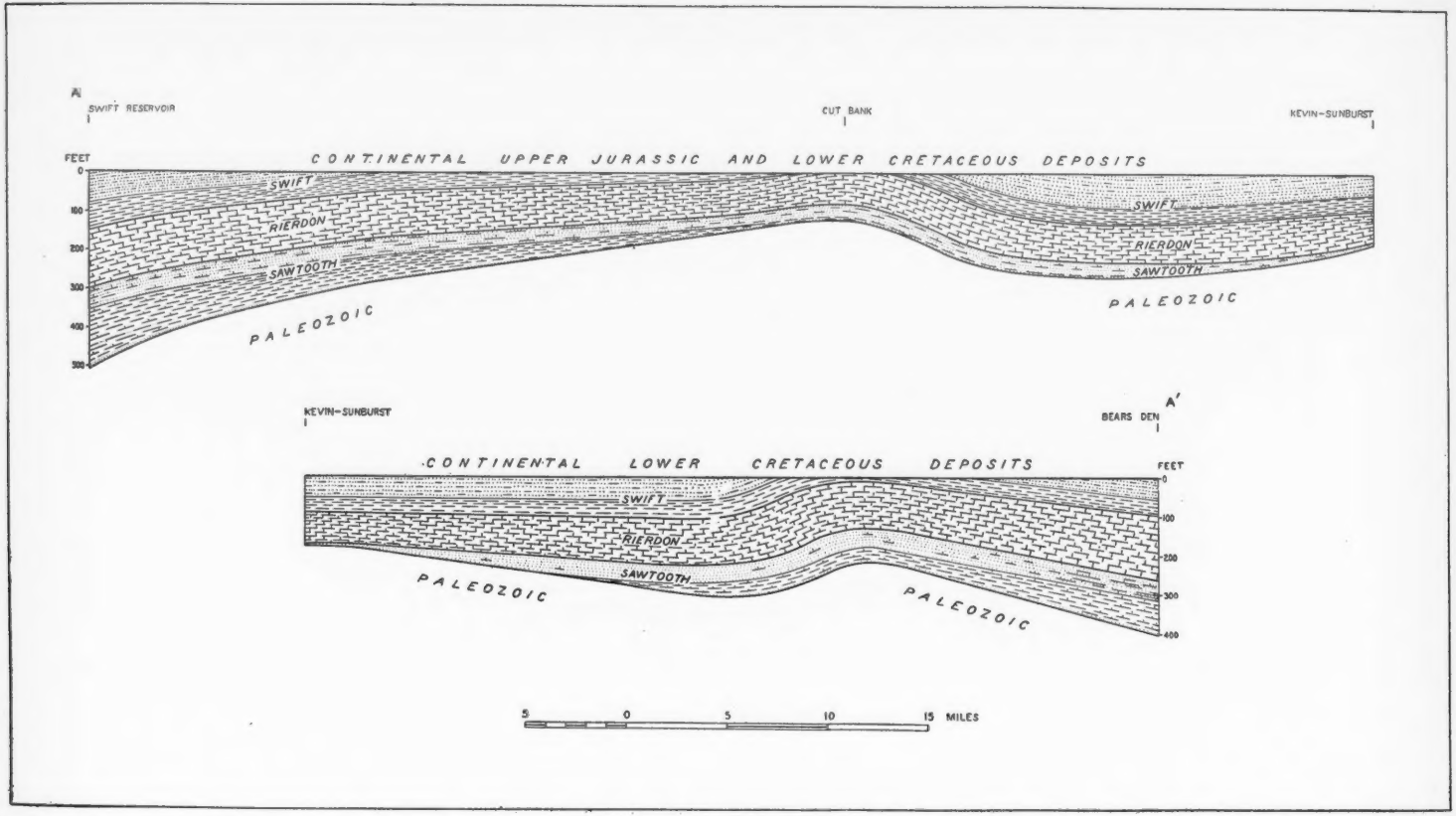

FIG. 5.—Cross section *AA'* showing thinning of Sawtooth and Rierdon formations over Kevin-Sunburst dome, and relationship of marine Jurassic rocks with continental Upper Jurassic and Lower Cretaceous deposits.

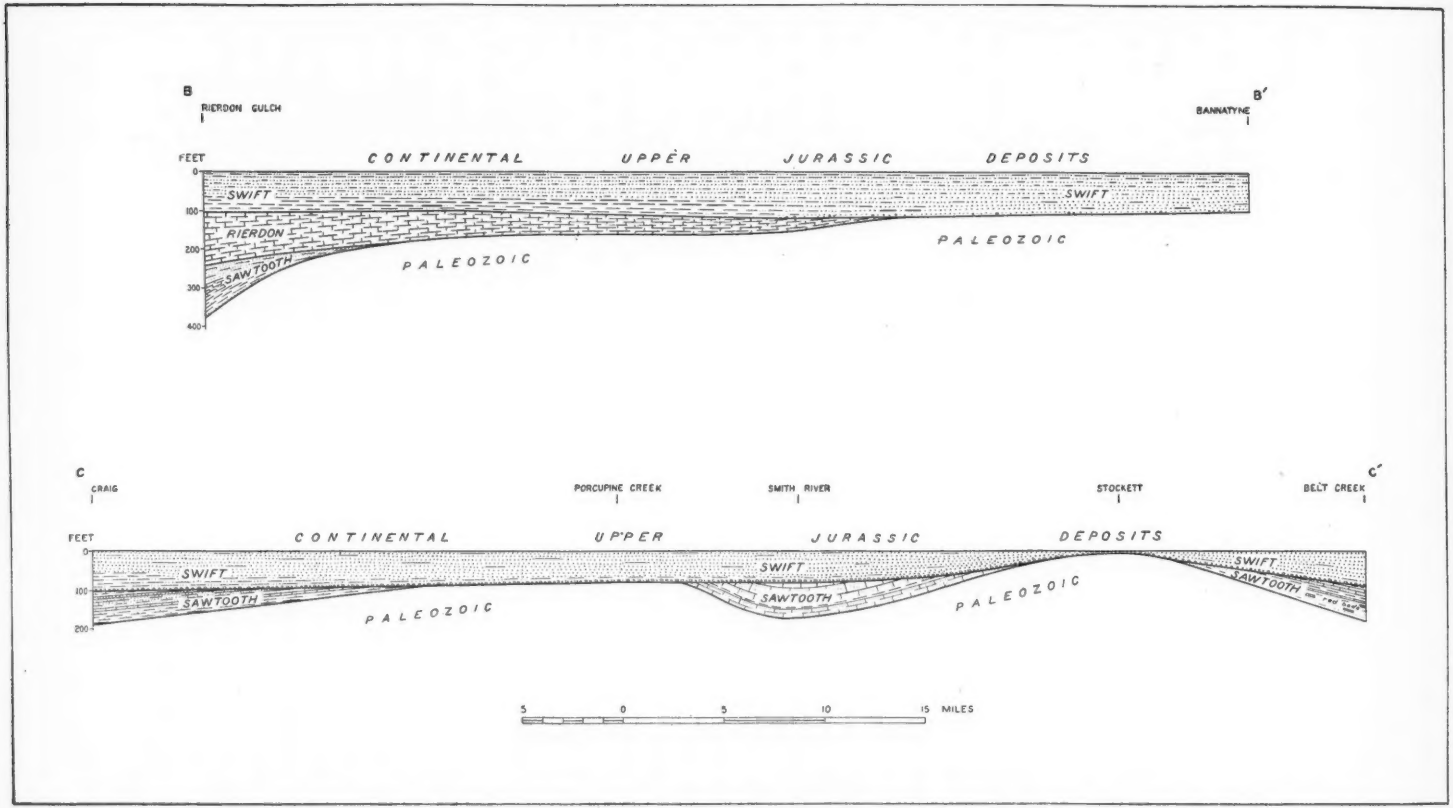

FIG. 6.—Cross sections *BB′* and *CC′*. Cross section *BB′* shows eastward thinning of Sawtooth and Rierdon formations upon South arch. Cross section *CC′* shows Swift-Sawtooth unconformity across southern part of South arch, and thinning of Swift formation in Stockett area.

of the Rierdon was removed from the Kevin-Sunburst dome and along the Rocky Mountain Front. The pronounced thinning of the Rierdon in the area south of the Devon gas field (Fig. 3) is probably a result of early Divesian erosion.

By middle or late Divesian, marine waters had again transgressed the entire area. The deposits consisted of sand and dark mud. The abundance of ripple-marks, cross-bedding, and prints of driftwood indicate shallow-water deposition. The sediments became increasingly sandy south toward the Little Belt Mountain uplift.

At the beginning of the Kimmeridgian, the marine waters retreated from the area.[37] Continental deposition followed, in which dark greenish gray clay shale, variegated mudstone, fresh-water limestone, and very fine-grained lenticular beds of sandstone were formed conformably above the Swift sandstone. At a later date, probably at the close of the Jurassic, all of the Swift and part of the Rierdon were removed by erosion from parts of the Cut Bank and Whitlash areas before the deposition of the Cut Bank and Sunburst sandstones.

CONCLUSIONS

The marine Jurassic rocks of the Sweetgrass arch are divisible into three major lithologic units. The basal unit is chiefly sandstone, siltstone, sandy limestone, sandy oölite, and shale. The medial unit is largely limy shale and nodular limestone. The upper unit is dark non-calcareous micaceous shale and flaggy glauconitic sandstone. The writer proposes to give these units formational rank, naming them the Sawtooth, Rierdon, and Swift formations. The Sawtooth is of upper Bathonian age, the Rierdon of upper Bathonian and Callovian age, and the Swift of Divesian and Argovian age. Inasmuch as all, or most of, these beds have been included in the Ellis formation, the writer proposes to raise the Ellis to group rank.

The beds composing the Sawtooth and Rierdon formations and the shale member of the Swift have been assigned to the Ellis by all previous workers. The upper or sandstone member of the Swift has been variously treated as either part of the Ellis or the basal part of the Lower Cretaceous Kootenai formation.

Fine-grained continental deposits consisting chiefly of greenish gray clay shale and fresh-water limestone and which conformably overlie the Swift formation, have been included in the Ellis by some workers. These beds are assigned to the Morrison formation by the writer.

The Sweetgrass arch was a structural feature during the Bathonian and Callovian stages. It consisted of two major structures, the Kevin-Sunburst dome and the South arch. The axes of these structures almost coincide with the present axes. Most of the South arch remained above sea-level during the Bathonian and Callovian. The Kevin-Sunburst dome was submerged but remained high.

[37] Ralph W. Imlay, "Jurassic Formations of Gulf Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 11 (1943), p. 1526.

A pronounced unconformity occurs at the base of the Swift formation and represents early Divesian time. Parts of the Sawtooth and Rierdon formations were removed by erosion during this interval.

Possibilities for commercial accumulation of petroleum in the weathered surface of the Madison limestone on the Sweetgrass arch are negligible in the absence of the Sawtooth or Rierdon formations. The Cut Bank field has been localized where an unconformity has brought the Cut Bank sandstone into direct contact with the Rierdon.

LOCAL SECTIONS

The following sections are presented to show the general lithologic features of the Ellis group in the Sweetgrass arch area. The Rierdon Gulch and Swift Reservoir sections are typical of the Ellis along the Rocky Mountain Front north of Sun River. The Sun River section shows sandy beds in the shale member of the Swift formation. The section near Craig shows the character of the Swift nearly midway between the massive sandstone facies of the Little Belt Mountains and the shaly facies of the Rocky Mountain Front north of Sun River. The section on Belt Creek is presented mainly to show the gradation from Sawtooth to Gypsum Springs sediments. For the Ellis section in the Sweetgrass Hills, the reader is referred to Sanderson[38] or Russell and Landes.[39]

RIERDON GULCH SECTION

A section was measured through the Ellis by Deiss[40] on the divide between the heads of Rierdon and Slim gulches in the Sawtooth Range in the S. ½ of Sec. 23, T. 24 N., R. 9 W. Deiss shows a 33-foot covered unit in beds assigned to the siltstone member of the Sawtooth in this report. All of the Sawtooth is exposed at one place or another from the divide between the heads of Rierdon and Slim gulches northwest down Rierdon Gulch for ½ mile. In order to show more detail and the divisions of the Ellis, the writer measured and described the following section in the W. ½ of Sec. 23, T. 24 N., R. 9 W. This section is the type for the Sawtooth and Rierdon formations. With the exception of the massive bed of fine-grained sandstone at the base of the upper or sandstone member of the Swift, the lithologic characteristics of the formation are very similar with the Swift at Swift Reservoir. In Rierdon Gulch the Swift is conformably overlain by greenish gray clay shale with dense gray limestone nodules and dark gray shale containing charophyte oögonia and ostracods which appear to be of Morrison age.[41]

[38] Sanderson, *op. cit.*

[39] Russell and Landes, *op. cit.*

[40] Deiss, *op. cit.*

[41] Examined by Raymond E. Peck.

	Feet	Inches
Swift formation		
Sandstone member		
41. Sandstone and shale: light gray fine- to very fine-grained sandstone in thin hard ripple-marked flags containing black-gray micaceous shale films; much interbedded with black-gray micaceous shale containing light gray sandy streaks. Lower 15 feet contains some dark coarse-grained sandstone flags, in places pebbly. Trails or burrows present throughout unit. Sandstone and shale, hard, forming cliffs stained rusty brown. Shale surfaces weathered bluish gray	40	
40. Sandstone: medium gray, fine-grained, calcareous, massive, non-bedded. Varies greatly in thickness. Very hard; forms cliff	16	
39. Sandstone and shale: medium gray fine-grained sandstone interbedded with black-gray micaceous fissile shale. Lenticular		8
38. Sandstone: light gray weathering drab brown, very fine-grained, massive, unbedded, hard	6	
Shale member		
37. Shale: dark gray, very finely micaceous, rather chunky, firm; contains very hard slightly calcareous siltstone partings, large tan-weathering calcareous concretions, and smaller brown-weathering clay ironstones	43	6
36. Shale: dark gray, chunky, highly glauconitic; contains water-worn belemnites and rarely black chert granules		6
Total thickness of Swift formation	106	8
Unconformity		
Rierdon formation		
Upper limy shunky shale member		
35. Limestone and shale: medium gray with olive-green cast. About 15 buff-weathering, gray dense limestone layers 2 to 6 inches thick alternating with limy chunky shale forming a banded outcrop. Numerous fossils, chiefly *Gryphaea nebrascensis* Meek and Hayden	39	
34. Shale: medium gray with olive-green cast, very limy, chunky; contains a row of distantly spaced white barite concretions as much as 10 inches in diameter 3 feet above the base	18	6
33. Shale: medium gray, limy, chunky; contains beds of hard buttress-forming shale, and in places, shaly nodular limestone	25	
Fissile shale member		
32. Shale: medium gray with olive-green cast but slightly darker than overlying units, fissile. Contains 10 limy chunky shale beds forming buttresses and which contain 8 buff-weathering nodular limestones 4 to 8 inches thick. Upper part most calcareous, and contains a few white barite nodules as much as 2 inches in diameter	27	
31. Shale: medium gray with olive-green cast, limy, chunky. Contains 2 buff-weathering nodular limestones at top and bottom, each overlain by 1-inch layers of rusty shale containing water-worn *Gryphaea impressimarginata* McLearn	3	
30. Shale: medium gray with olive-green cast but darker than underlying and overlying units, fissile, slightly calcareous	3	6
Lower limy chunky shale member		
29. Shale: medium gray with olive-green cast, limy, chunky; contains a few dense gray nodular limestones. Fossiliferous	20	6
Total thickness of Rierdon formation	136	6
Sawtooth formation		
Siltstone member		
28. Bentonite: light gray, highly limonitic		1
27. Limestone: medium gray, silty, very finely pyritic, hard, shaly; contains comminuted fossils and traces of glauconite	1	
26. Siltstone: light gray weathering orange tan, highly calcareous, very finely glauconitic and limonitic; contains numerous *Camptonectes*	3	
25. Siltstone: light gray weathering orange tan, calcareous, very finely glauconitic and limonitic; in hard and soft beds 1 foot to less than 1 inch in thickness. Fossiliferous	19	6
24. Siltstone: light gray weathering orange tan, calcareous, very finely glauconitic and limonitic; in hard beds averaging 1 foot in thickness separated by shaly partings	4	2

	Feet	*Inches*
23. Siltstone: medium gray, calcareous, shaly, soft	2	6
22. Siltstone: medium gray weathering orange tan, calcareous, very finely glauconitic and limonitic, more or less thick-bedded and massive; contains abundant *Pleuromya* and *Camptonectes*	7	
21. Shale: medium gray, chunky	1	
20. Shale: medium gray, bentonitic		1
19. Shale and siltstone: dark medium gray soft silty chunky shale; brownish-weathering calcareous, very finely limonitic chunky siltstone. Fossiliferous	4	
18. Siltstone: medium gray weathering orange tan, calcareous; in 4- to 18-inch beds; contains abundant *Pleuromya*	4	
17. Shale and siltstone: dark medium gray non-calcareous fissile shale interbedded with buff- and brown-weathering hard and soft calcareous siltstone containing black phosphatic pellets. Fossiliferous	5	6
Shale member		
16. Shale: dark medium gray, non-calcareous, fissile	5	6
15. Bentonite: light gray, shaly		1
14. Shale: medium gray, fissile, more or less calcareous; contains numerous light gray- to buff-weathering, medium gray limestone nodules, and many black phosphatic pellets. Fossiliferous	11	
13. Shale and bentonite: light to medium gray, micaceous	1	
12. Shale: medium gray, limy, chunky, very finely pyritic; weathers to light bluish gray buttress	7	
11. Shale: medium drab gray, calcareous, chunky to fissile	19	6
10. Limestone: dark medium gray weathering light bluish gray and buff, dense		6
9. Shale: medium drab gray, non-calcareous to slightly calcareous, silty, chunky; contains very fine sandy partings often crowded with black phosphatic pellets	5	
8. Shale: dark gray, fissile, and non-calcareous to medium drab gray, chunky, and calcareous. Some bedding planes stained yellow	8	
7. Limestone: dark medium gray-weathering light bluish gray, dense, minutely pyritic	1	
6. Shale: medium drab gray, calcareous, soft, fairly fissile. Some bedding planes stained yellow	10	
5. Limestone and siltstone: dark medium gray, dense, very finely pyritic, hard; in two beds	1	
4. Shale: dark medium gray, fissile; bedding planes stained yellow Lower part contains brownish-weathering finely micaceous shaly siltstone partings, and rarely light gray very fine-grained quartz sandstone Upper part soft and possibly bentonitic	8	
3. Limestone: dark medium gray, dense; weathers light bluish gray. Top surface occasionally contains black phosphatic pellets less than 3 mm. in length		6
2. Shale: black gray to dark medium gray, noncalcareous, fissile. Bedding surfaces in lower part stained yellow. Contains a few thin shaly fine-grained sandstone partings in lower part, and in places lenses of black phosphatic pellets	5	
Sandstone member		
1. Sandstone: light gray more or less stained brown, very fine-grained, calcareous, very finely pyritic. Composed chiefly of angular to subangular colorless quartz. Massive and thick-bedded to thin-bedded or shaly; ordinarily ripple-marked. Locally contains black phosphatic pebble lenses. Thickness variable; rests unconformably on Hannan limestone	1	8
Total thickness of Sawtooth formation	136	7
Total thickness of Ellis group	379	9

SWIFT RESERVOIR SECTION

The following section is composite from measurements made in the immediate vicinity of Swift Reservoir in T. 28 N., R. 10 W., Pondera County. The section is the type for the Swift formation, which was measured on the north shore in the NE. $\frac{1}{4}$ of Section 27. The Swift is overlain conformably by Morrison green cal-

careous clay shale containing a fresh-water limestone at the base and several tan-weathering fine-grained lenticular sandstone beds higher in the section. The Rierdon formation and the basal sandstone member of the Sawtooth were measured in a gulch east of Swift Reservoir in the SW. ¼ of Section 26 where the Sawtooth rests unconformably on the Hannan limestone. The rest of the Sawtooth was measured along the north shore of the reservoir just northeast of the Swift section. When the reservoir is low, the Rierdon is exposed along the water's edge.

	Feet	*Inches*
Swift formation		
Sandstone member		
46. Sandstone: gray, fine-grained, thick- and thin-bedded; contains some black-gray ripple-marked micaceous shale partings. Resistant, forms upper part of ledge	14	
45. Sandstone and shale: gray fine- to very fine-grained hard sandstone in thin ripple-marked flags containing abundant black-gray micaceous shale films; much interbedded with bluish-weathering, black-gray micaceous shale. Unit contains numerous burrows or trails. Resistant, forms ledge stained brownish	40	
44. Sandstone: gray, fine-grained; in thin hard ripple-marked flags containing black-gray micaceous shale films	21	
43. Sandstone: dark gray, coarse-grained, ripple-marked, hard; composed chiefly of angular colorless quartz and subangular black and gray chert		8
42. Shale: dark gray, hard; contains ripple-marked micaceous siltstone partings with burrows and trails	4	
41. Conglomerate: dark gray, hard, lenticular. Composed of small black chert pebbles and water-worn belemnites with lesser amounts of oyster fragments, calcareous worm(?) tubes, fish teeth, and glauconite in a fine calcareous, sandy matrix		7
Shale member		
40. Shale: dark gray with slight greenish cast, very finely micaceous, firm; contains thin layers of hard gray calcareous siltstone more or less ripple-marked. Few large bright rusty tan-weathering, dark gray hard calcareous concretions. Rarely a thin lenticular bed composed of fragments of belemnites and calcareous worm(?) tubes	7	
39. Shale: dark gray with slight greenish cast, very finely micaceous, firm, non-calcareous; contains rusty brown-weathering, dark gray hard calcareous concretions as much as 3 feet in diameter, and smaller soft limonitic concretions. Some pelecypod impressions in shale	47	
38. Sandstone: greenish, fine-grained, highly glauconitic; contains here and there round black chert pebble as much as ¼ inch in diameter, and water-worn belemnites		6
Total thic ness of Swift formation	134	9
Unconformity		
Rierdon formation		
37. Shale: largely medium gray with olive-greenish cast, limy; dark slightly calcareous to non-calcareous fissile member in lower part. Contains many buff-weathering 4- to 10-inch layers of medium gray hard dense nodular limestone, and beds of hard limy shale weathering to buttresses. Fossiliferous. Upper part contains large white barite concretions	140±	
Total thickness of Rierdon formation	140±	
Sawtooth formation		
Siltstone member		
36. Siltstone: light gray weathering bluish gray to buff, highly calcareous, very finely glauconitic and pyritic, thick- and thin-bedded, hard. Fossils rare, chiefly *Gryphaea impressimarginata* McLearn	30+	
35. Siltstone: gray to buff gray, calcareous, poorly bedded; contains abundant pelecypods	2	6

	Feet	Inches
34. Siltstone: gray weathering tan, calcareous, very finely pyritic, rather massive; some fine cross-bedding	11	6
33. Siltstone: medium gray, calcareous	4	
32. Shale and siltstone: medium gray, calcareous, chunky	2	
31. Siltstone: medium gray, calcareous	1	10
30. Shale and siltstone: medium gray, calcareous, soft, chunky. Fossiliferous, chiefly *Pleuromya*	3	6
29. Siltstone: medium gray weathering brown, calcareous, hard, fossiliferous	1	
28. Siltstone: medium gray, calcareous, fossiliferous; contains black phosphatic pebbles as much as ⅜ inch in diameter	1	6
Shale member		
27. Shale: dark medium gray with olive-green cast, calcareous, chunky. Bedding surfaces stained purple and brown	5	
26. Shale: dark gray with olive-green cast, non-calcareous, fissile	6	
25. Shale: dark medium gray with olive-green cast, calcareous, chunky. Bedding surfaces stained purple	4	6
24. Limestone: dark medium gray, dense, hard, nodular; weathers brownish		6
23. Shale: dark medium gray with olive-green cast, fissile, noncalcareous	4	
22. Limestone: drab gray, silty, hard; weathers brown; contains a few black phosphatic pellets and pelecypods		8
21. Shale: lower part black-gray, non-calcareous, fissile; upper part dark medium gray, slightly calcareous, less fissile	50±	
20. Shale: dark medium gray, calcareous, chunky; contains black phosphatic pellets at base	3	
19. Shale: dark gray, noncalcareous, fissile	2	
18. Shale: dark gray, limonitic; contains black phosphatic pellets and fragments of small oysters and other pelecypods		1
17. Shale: dark medium gray with slight olive-green cast, calcareous, chunky; contains a few black phosphatic pellets. Bedding surfaces stained purple	9	6
16. Shale: dark gray; contains abundant small black phosphatic pellets and a few pelecypods		2
15. Shale: dark medium gray with slight olive-green cast, slightly calcareous, fissile; contains some pelecypod impressions. Bedding surfaces stained purple	10	6
14. Shale: dark medium gray with slight olive-green cast, calcareous, chunky	3	
13. Shale: dark medium gray with slight olive-green cast, calcareous, chunky to fissile; contains scattered gray calcareous clay pebbles coated purplish black, and as much as 3 inches in diameter	4	
12. Concretions: dark gray weathering brown, calcareous, dense, hard		6
11. Shale: medium gray, fissile. Bedding surfaces stained brown	2	6
10. Shale: black gray, non-calcareous, fissile. Bedding surfaces stained yellow	8	
9. Conglomerate: black phosphatic pebbles as much as 1 inch in diameter and water-worn belemnites in a pyritic, calcareous, siltstone matrix. Weathers rusty brown		4
8. Shale: dark gray		1
7. Concretions: gray, calcareous, clayey		6
6. Shale: dark bluish gray, non-calcareous, fissile; contains scattered small buff-gray clayey nodules and water-worn belemnites in upper part. Bedding surfaces stained yellow	7	
5. Conglomerate: black phosphatic pebbles as much as ¼ inch in diameter and water-worn belemnites in drab-buff calcareous siltstone		4
4. Shale: black gray, non-calcareous, fissile; contains some sandy and glauconitic streaks	10±	
Sandstone member		
3. Sandstone: medium gray weathering tan, very fine-grained, calcareous, thick- and thin-bedded; contains pelecypods and belemnites	5	
2. Sandstone: medium gray, very fine-grained, calcareous, thin-bedded; contains ripple-marked dark gray sandy, shale partings	2	
1. Clay: gray, siliceous; contains rusty brown porous limonitic nodules	1	
Total thickness of Sawtooth formation	198±	
Total thickness of Ellis group	472±	

SUN RIVER SECTION

This section was measured in a gulch south of the North Fork of Sun River in the SW. ¼ of Sec. 36, T. 22 N., R. 9 W., Lewis and Clark County. The Swift formation is overlain conformably by greenish clay shale and mudstone of the Morrison. The Sawtooth rests unconformably on the Hannan limestone.

	Feet	*Inches*
Swift formation		
Sandstone member		
13. Sandstone: medium gray to buff, fine-grained, calcareous, thin-bedded, more or less finely cross-bedded; some ripple-marks; weathers tan. Resistant, forms top of hogback	20	
12. Sandstone and shale: gray fine- to very fine-grained sandstone in thin hard ripple-marked flags containing abundant black-gray micaceous shale films; much interbedded with black-gray micaceous shale containing gray sandy streaks. Sandstone and shale contain numerous trails and burrows. Unit is resistant forming cliffs stained rusty brown. Shale weathers bluish	60	
Shale member		
11. Limestone: dark gray weathering brown, dense, hard, concretionary; grades upward into fine-grained calcareous sandstone	2	
10. Shale: dark gray, more or less sandy; contains many thin lenses of fine-grained gray sandstone	15	
9. Concretions: gray weathering reddish brown, calcareous, dense, ferruginous	1	
8. Shale: dark gray; contains thin fine-grained ripple-marked sandstone lenses. Lower 7 feet very sandy	20	
7. Sandstone: greenish, fine-grained, highly glauconitic, soft. Base locally crowded with water-worn belemnites		6
Total thickness of Swift formation	118	6
Unconformity		
Rierdon formation		
6. Shale: medium greenish gray, limy, largely chunky; contains many thin beds of buff-weathering, gray dense, hard limestone. Fossiliferous	121	
Total thickness of Rierdon formation	121	
Sawtooth formation		
Siltstone member		
5. Siltstone: medium gray, thick- and thin-bedded, calcareous, fossiliferous, hard. Lower part contains dark sandy shale layers	25	
Shale member		
4. Shale: dark gray, slightly calcareous	11	
3. Shale: dark gray, calcareous, massive, fossiliferous; weathers buff	1	
2. Shale: dark gray, calcareous, finely sandy	6	
Sandstone member		
1. Sandstone: light to medium gray, very fine-grained, calcareous, hard, massive, fossiliferous	4	
Total thickness of Sawtooth formation	47	
Total thickness of Ellis group	286	6

CRAIG SECTION

The following section was measured 2.3 miles by road southwest of Craig in a ravine west of the road in the SW. ¼ of Sec. 16, T. 15 N., R. 3 W. The section lies a few hundred feet southwest of a major fault thrusting Mississippian rocks upon the Upper Cretaceous. Limestones in the lower part of the Sawtooth are brecciated and shales show slaty cleavage. These disturbed limestones and shales of

the lower Sawtooth were not measured inasmuch as true thicknesses and bedding character could not be determined. The sandstone member of the Swift is in fault contact with the underlying shale member resulting in the omission of some of the shale. About ½ mile southwest of the section and higher on the mountain, Imlay[42] measured a total thickness of 90 feet for the shale member of the Swift. The Morrison overlies the Swift.

	Feet	*Inches*
Swift formation		
Sandstone member		
20. Sandstone: yellowish tan-weathering, largely fine-grained, thick- and thin-bedded, slightly glauconitic; some cross-bedding and ripple-marks; contains some prints of driftwood. Resistant, forming massive cliffs	55	
Fault contact		
Shale member		
19. Shale: dark gray, micaceous, hard; contains abundant lenses of fine- to very fine-grained glauconitic sandstone containing bluish-weathering shale films and trails or burrows	13	
18. Shale: dark gray, finely micaceous, firm; contains some very fine-grained sandy streaks especially in the upper 5 feet	24	6
17. Sandstone and shale: light to medium gray very fine-grained sandstone lenses commonly less than one inch in thickness interbedded with dark gray very finely micaceous shale. Weathers to brownish ledge	8	4
16. Conglomerate: rounded pebbles and cobbles of tan quartzite and dark gray chert as much as 7 inches in diameter with smaller pebbles of limestone; in matrix of calcareous fine-grained sandstone		6
Total thickness of Swift formation	101+	
Unconformity. Rierdon formation absent		
Sawtooth formation		
Siltstone member (largely silty or sandy limestone)		
15. Limestone: medium gray weathering yellowish to brown, sandy, massive; contains comminuted fossils	4	
14. Limestone, shale, and siltstone: brownish-weathering, sandy; in layers 6 to 10 inches in thickness; forms cliff	4	6
13. Shale: dark gray, somewhat chunky	8	6
12. Limestone: medium gray, sandy, oölitic, hard, massive. Composed of a dense buff silty, limy matrix containing dark medium gray calcareous oölites, subangular to subrounded colorless quartz grains, some subangular black chert grains, and comminuted fossils	3	6
11. Shale: medium gray, bentonitic		7
10. Limestone: medium gray weathering bright tan, silty to very finely sandy; in thick and thin beds	12	
9. Shale: medium gray, bentonitic		5
8. Shale: medium to dark gray, chunky		5
7. Limestone: medium gray weathering tan, finely sandy, thick-bedded	1	6
6. Sandstone and shale: light gray very fine-grained flaggy sandstone composed almost entirely of subangular to subrounded colorless quartz grains; and dark gray sandy shale		8
5. Limestone: medium gray weathering tan, more or less finely sandy; in beds 1 to 10 inches in thickness separated by shaly limestone, medium gray limy chunky shale, or black-gray fissile noncalcareous shale	9	
4. Shale: dark medium gray weathering bluish gray or buff, limy, slaty cleavage		
3. Limestone: medium gray weathering tan buff. Lower part sandy and very finely pyritic.		
2. Shale: dark medium gray weathering bluish gray or buff, limy, slaty cleavage		
1. Limestone: medium gray, hard, massive, brecciated		
Total thickness of measured Sawtooth	45	1
Total thickness of Ellis group	146+	

[42] Personal communication.

BELT CREEK SECTION

The Ellis is exposed along both sides of Belt Creek valley 8 to 9 miles south of Belt. A completely exposed section does not occur at any one place, and in general, the outcrops are slumped. The following section is composite from measurements made in a cut in Highway No. 89 in the SE. $\frac{1}{4}$ of Sec. 36, T. 18 N., R. 6 E., along the east side of Belt Creek and in an old highway cut in the SE. $\frac{1}{4}$ of Sec. 36, T. 18 N., R. 6 E., and on the west side of Belt Creek in the E. $\frac{1}{2}$ of Sec. 2, T. 17 N., R. 6 E. The Sawtooth equivalent overlies unconformably the Otter shale of the Big Snowy group. The Swift formation is overlain conformably by green clay shale of the Morrison.

	Feet	*Inches*
Swift formation		
22. Sandstone: tan weathering, fine- to medium-grained, thick- and thin-bedded, locally cross-bedded; contains wood impressions. Finer-grained and thinner-bedded toward the top. Composed chiefly of angular to subangular colorless quartz grains and minor amounts of medium to dark gray chert. Joint faces in middle of unit coated with dark desert varnish displaying many colors. Massive, forms bluffs	55	
21. Sandstone: tan weathering, fine- to very fine-grained; contains wood prints. Ripple-marked bedding surfaces contain micaceous shale films	13	
20. Sandstone: tan weathering, coarse-grained; contains lenses of conglomerate and scattered pebbles as much as 1.5 inches in diameter. Some prints of wood and partings of very fine-grained sandstone and siltstone	10	
19. Conglomerate: rounded to subrounded pebbles and cobbles of tan and gray quartzite and medium to dark gray chert as much as 5 inches in diameter; in tan fine- to coarse-grained hard calcareous sandstone. Contains some water-worn oyster shells	1	
Total thickness of Swift formation	79	
Unconformity. Rierdon formation absent		
Sawtooth equivalent		
18. Limestone: yellowish, dense, chalky; weathers brown	1	
17. Limestone: buff, soft, chalky, shaly. Few fossils	2	
16. Shale: light gray weathering bluish gray; contains some fossils and tiny green clay galls	1	
15. Limestone: light gray, dense, poorly bedded, highly fossiliferous; contains some sand grains and tiny green clay galls	5	
14. Limestone: medium gray, dense to finely crystalline, sandy, hard; in wavy beds averaging 2 feet in thickness; weathers brownish; contains a few thin green shale parting. Upper part contains abundant fragments of *Pentacrinus*	14	
13. Shale: medium green, limy		6
12. Limestone: light gray, dense, massive; weathers yellowish tan	2	
11. Shale: medium green, limy	1	6
10. Limestone: medium gray to slightly reddish gray, very finely crystalline to coarsely crystalline	2	2
9. Limestone and shale: yellowish and green, soft, poorly bedded. Much limestone and shale conglomerate	2	2
8. Limestone: creamy buff, dense, hard; weathers yellowish		9
7. Shale: medium green, limy	3	6
6. Limestone: medium gray, dense, fossiliferous; in beds 6 inches to 2 feet thick; weathers yellowish tan	5	
5. Shale: medium green, limy	6	
4. Shale and siltstone: maroon, green, and yellow, sandy, calcareous, gypsiferous. Some thin yellowish oölitic limestones in lower part	26	
3. Siltstone and limestone: massive pale gray calcareous siltstone grading up into creamy buff oölitic limestone	6	

	Feet	Inches
2. Siltstone: light gray to buff, calcareous, hard and soft; contains a few sand grains	6	
1. Siltstone: light gray to buff, calcareous, massive, poorly bedded to non-bedded; contains scattered colorless quartz grains. Basal part contains large fragments of limestone derived from Otter formation	7	
Total thickness of Sawtooth equivalent	90	7
Total thickness of Ellis group	169	7

ELLIS WELL LOGS

The following well logs are presented to show the general lithologic features of the Ellis group in the Bannatyne, Pondera, Midway, Cut Bank, and Kevin-Sunburst oil and gas fields. In the Bannatyne, Pondera, and Midway fields the Swift formation is overlain conformably by green or greenish gray clay shale of the Morrison. In the Cut Bank field the Cut Bank sandstone rests unconformably on the shale member of the Swift in Hannah-Porter's Marceau No. 1, and unconformably on the Rierdon in the Carter's Tribal No. 25. The Parrent's McAlpine No. 1 is several miles north of the Kevin-Sunburst field, but the lithologic features of the Ellis are typical of the field. In the McAlpine well the Swift formation is overlain unconformably by light greenish gray and lavender-gray sandy bentonitic mudstone of the Sunburst zone.

BANNATYNE FIELD. GENOU OIL COMPANY'S SPEER NO. 1, SEC. 8, T. 25 N., R. 1 E.

	Depth in Feet	Thickness in Feet
Swift formation (lower part)		
Sandstone: medium gray, coarse-grained, poorly sorted, porous. Composed almost entirely of angular colorless quartz and black chert with a little bluish gray or white chert and very little pyrite. Contains some black-gray micaceous shale partings with fine-grained glauconitic sandy streaks	1,450–1,460	10
Sandstone: dark gray, coarse- to very coarse-grained, porous. Grain size and proportion of dark chert increases toward base where pebbles of dark chert as much as $\frac{1}{4}$ inch in diameter are present, and sandstone is black and pyritic	1,460–1,525	65
Unconformity		
Madison limestone		

PONDERA FIELD. ELLIOTT *et al.* JONES NO. 1, SEC. 17, T. 27 N., R. 4 W.

	Depth in Feet	Thickness in Feet
Swift formation		
Sandstone member		
Sandstone: light gray, fine-grained, thin-bedded, glauconitic; contains black-gray micaceous shale films. Basal 1 or 2 feet medium- to coarse-grained and pyritic	1,850–1,871	21
Shale: dark gray, finely micaceous; contains thin streaks of light gray very fine-grained slightly glauconitic sandstone	–1,894	23
Sandstone and shale: medium gray fine-grained thin-bedded glauconitic sandstone interbedded with dark gray micaceous shale. Base is medium- to coarse-grained pyritic chert sandstone	–1,920	26

	Depth in Feet	Thickness in Feet
Shale member		
Shale: dark gray, finely micaceous; contains some partings of very fine-grained slightly glauconitic sandstone and fragments of drab-brown clay ironstone. Lower 30 feet pyritic. Basal few inches highly glauconitic and pyritic	−2,016	96
Total thickness of Swift formation		166
Unconformity		
Rierdon formation		
Shale and limestone: medium gray, finely pyritic, dense. Contains fragments of *Gryphaea*	−2,035	19
Total thickness of Rierdon formation		19
Total thickness of Ellis group		185
Unconformity		
Madison limestone		

MIDWAY FIELD. R. C. TARRANT'S WOOD NO. 1, SEC. 32, T. 28 N., R. 1 W.

	Depth in Feet	Thickness in Feet
Swift formation		
Sandstone member		
Sandstone: light to medium gray, very fine-grained, slightly glauconitic; contains abundant dark gray micaceous shale films	1,795–1,817	22
Sandstone: light to dark gray, fine- to medium-grained, slightly glauconitic and pyritic, hard; contains dark micaceous shale films	−1,820	3
Sandstone: light gray, fine-grained, glauconitic; contains dark micaceous shale films	−1,830	10
Samples missing. Should be glauconitic sandstone with dark micaceous shale partings according to records of near-by wells	−1,865	35
Shale member		
Shale: dark gray, finely micaceous	−1,900	35
Shale: dark gray, finely micaceous; contains very fine hard pyritic siltstone partings. Becomes increasingly pyritic toward base	−1,940	40
Shale: dark gray	−1,950	10
Total thickness of Swift formation		155
Unconformity		
Madison limestone		

SOUTH CUT BANK FIELD. HANNAH-PORTER'S MARCEAU NO. 1, SEC. 3, T. 31 N., R. 6 W.

	Depth in Feet	Thickness in Feet
Swift formation		
Shale member		
Shale: dark gray, very finely micaceous; contains a few pyritic spots and rarely a slightly glauconitic siltstone parting	3,090–3,107	17
Total thickness of Swift formation		17
Unconformity		
Rierdon formation		
Upper limy chunky shale member		
Shale and limestone: medium gray limy shale with faint greenish cast; light to medium gray dense limestone	−3,110	3

	Depth in Feet	Thickness in Feet
Shale: medium gray with faint greenish cast, limy. Few thin layers of dense minutely pyritic limestone. *Gryphaea* fragments. Shale and limestones contain some scattered glauconite grains as much as 0.5 millimeter in diameter	−3,125	15
Shale: dark medium gray, calcareous. Few thin medium gray dense minutely pyritic limestone layers	−3,160	35
Dark fissile shale member		
Shale: dark gray, slightly calcareous to non-calcareous, fissile, very finely pyritic. Much light gray dense limestone in lower 5 feet	−3,175	15
Lower limy chunky shale member		
Shale and limestone: medium gray limy minutely pyritic shale; medium gray dense minutely pyritic limestone	−3,197	22
Total thickness of Rierdon formation		90
Sawtooth formation		
Siltstone member		
Siltstone or silty limestone: light to medium gray, limy, finely pyritic, hard, fossiliferous; contains a few scattered glauconite grains	−3,211	14
Siltstone and shale: medium gray, calcareous, finely pyritic	−3,223	12
Shale member		
Shale: dark gray to black gray, non-calcareous, fissile, finely pyritic. Few thin layers of brownish gray dense finely pyritic limestone. Some dark gray phosphatic pellets	−3,236	13
Sandstone member		
Siltstone: very light gray, non-calcareous, very finely pyritic, hard; contains light gray chert pebbles	−3,238	2
Total thickness of Sawtooth formation		41
Total thickness of Ellis group		148
Unconformity		
Madison limestone		

NORTH CUT BANK FIELD. CARTER'S TRIBAL NO. 25, SEC. 27, T. 36 N., R. 6 W.

	Depth in Feet	Thickness in Feet
Rierdon formation		
Upper limy chunky shale member		
Shale: medium greenish gray, limy soft	3,152–3,160	8
Shale: medium greenish gray, limy. Several thin light to medium gray dense limestone layers with some pyritic spots. Shale and limestones contain a few scattered glauconite grains as much as 0.7 millimeter in diameter, and fragments of *Gryphaea*	−3,180	20
Shale: medium greenish gray, limy. Some thin beds of medium gray dense limestone. Fragments of *Gryphaea*	−3,200	20
Dark fissile shale member		
Shale: dark gray, slightly calcareous to non-calcareous, very finely pyritic, fissile. Much light gray minutely pyritic dense limestone	−3,221	21
Lower limy chunky shale member		
Shale: medium greenish gray, limy, minutely pyritic. Much medium gray minutely pyritic dense limestone. Few fragments of *Gryphaea*	−3,230	9
Shale: medium greenish gray, limy, minutely pyritic. Some medium-gray minutely pyritic dense limestone and darker pyritic, slightly glauconitic fossiliferous limestone	−3,240	10
Total thickness of Rierdon formation		88

	Depth in Feet	Thickness in Feet
Sawtooth formation		
Siltstone member		
Limestone: light gray, silty, finely pyritic, slightly glauconitic, hard; contains fragments of *Gryphaea*. At top a thin layer of limy very fine-grained sandstone containing gray chert granules	−3,245	5
Siltstone: medium gray, limy, very finely pyritic, hard, thin-bedded; contains an occasional glauconite grain. Some interbedded dark gray shale	−3,270	25
Shale: dark medium gray, very slightly calcareous	−3,280	10
Limestone and shale: light to medium gray very finely sandy, glauconitic hard limestone containing black phosphatic pellets, pyritic spots, and fragments of *Gryphaea;* interbedded with dark gray shale. Pyritic limestone at base	−3,286	6
Shale member		
Shale: dark gray to black gray, slightly calcareous to non-calcareous; some parts very finely pyritic; contains an occasional finely pyritic sandy layer and a few black phosphatic pellets	−3,313	27
Sandstone member		
Sandstone: light gray, calcareous, very slightly porous; composed of fine to very fine colorless quartz grains with a few coarse colorless quartz grains and pelecypod fragments. Contains films of black-gray shale and some pyritic spots. Base of sandstone is fine-grained, glanconitic, and porous, and contains large light and dark gray chert pebbles	−3,317	4
Total thickness of Sawtooth formation		77
Total thickness of Ellis group		165
Unconformity		
Madison limestone		

KEVIN-SUNBURST DOME. R. G. PARRENT'S MCALPINE NO. 1, SEC. 25, T. 37 N., R. 3 W.

	Depth in Feet	Thickness in Feet
Swift formation		
Sandstone member		
Sandstone: very light gray, fine- to very fine-grained, clayey; contains abundant light gray micaceous shale films. Composed chiefly of colorless quartz grains cemented by white clay with spots of brown siderite. Unit may be a facies of the Sunburst sandstone	1,876–1,895	19
Sandstone: light gray, very fine-grained; contains abundant black micaceous shale films. Composed of colorless quartz grains and some black chert grains. White clay cement	−1,905	10
Sandstone: light gray, fine-grained, slightly glauconitic; contains abundant black-gray micaceous shale films, and brown sideritic(?) spots. Contains more black chert than overlying unit and less white clay cement. Little pyrite	−1,925	20
Sandstone and shale: light gray fine- to very fine-grained slightly glauconitic sandstone much interlaminated with black-gray micaceous shale. Rarely a medium-grained lens of sandstone containing much black subangular chert	−1,935	10
Shale member		
Shale: dark gray, very finely micaceous. Upper part contains glauconitic streaks and some pyrite. Lower part contains brown glauconitic clay ironstone. Base is highly glauconitic	−1,950	15
Total thickness of Swift formation		74

	Depth in Feet	Thickness in Feet
Unconformity		
Rierdon formation		
Upper limy chunky shale member		
Shale: medium gray to greenish gray, limy, chunky	−1,975	25
Shale and limestone: medium gray limy shale; light to medium gray dense limestone. Contains a few scattered glauconite grains as much as 0.7 millimeter in diameter	−1,985	10
Dark fissile shale member		
Shale: dark medium gray, calcareous, fissile. Many gray dense limestone layers. Some parts very finely pyritic. Unit is gradational into overlying unit	−2,000	15
Lower limy chunky shale member		
Shale and limestone: medium gray, limy, dense	−2,010	10
Shale: medium greenish gray, limy, minutely pyritic. Few thin medium greenish gray dense limestone layers	−2,020	10
Shale and limestone: medium greenish gray limy shale; medium gray finely pyritic dense limestone	−2,030	10
Total thickness of Rierdon formation		80
Sawtooth formation		
Siltstone member		
Siltstone or silty limestone: light to medium gray, very finely pyritic, hard; contains pelecypod fragments and a few scattered glauconite grains. Rarely a gray chert pebble at top	−2,043	13
Siltstone: light gray, limy, very finely glauconitic and pyritic. Trace of whitish-gray minutely pyritic bentonite	−2,048	5
Siltstone and shale: medium gray, calcareous, very finely pyritic and sandy	−2,058	10
Siltstone: medium gray, calcareous, slightly glauconitic, very finely pyritic with some highly pyritic spots, thin-bedded to shaly; contains black phosphatic pellets	−2,065	7
Shale member		
Shale: black gray, non-calcareous, fissile, finely pyritic. Some bluish gray minutely pyritic, sandy bentonite	−2,068	3
Sandstone member		
Sandstone: light gray, coarsely fine-grained, porous; composed of angular to subangular colorless quartz grains. Contains light gray chert pebbles	−2,075	7
Total thickness of Sawtooth formation		45
Total thickness of Ellis group		199
Unconformity		
Madison limestone		

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RÉSUMÉ OF FACTS AND OPINIONS ON SEDIMENTATION IN GULF COAST REGION OF TEXAS AND LOUISIANA[1]

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ABSTRACT

Beginning with a description of sedimentary processes now in operation, this paper contrasts the heterogeneous deposits of the Mississippi delta with the structure of top-sets, fore-sets, and bottom-sets which the term "delta structure" usually implies. It describes the landward parts of the Pleistocene beds along the Gulf Coast as the coalescing deltaic deposits of many streams, producing a deltaic coastal plain as defined by D. C. Barton. It suggests that such structure is a feature of the shoreward parts of many of the older beds.

Proceeding to the offshore Recent and Pleistocene, the Ice age fall and rise of sea-level is discussed. It is stated that, beyond a certain distance from the present shore, deposition of sediments was continuous and that each interglacial rise of sea-level produced a tongue of deposits extending landward. This concept is extended to include the deposits of Tertiary time, during which there were changes of sea-level unrelated to the accumulation or melting of ice caps. A diagram is presented showing tongues of formation corresponding with incursions of the sea, while unconformities between the tongues, correspond with recessions of the sea.

It is stated that offshore belts of sand deposition correspond in position with currents which flow parallel with the shore. Sand does not gradually give place to mud as deposition proceeds seaward; but, in this case, sands alternate with muds out to 40 or 50 miles from shore.

Subsidence along with deposition is discussed as one of the most significant features of sedimentation in this region. It is suggested that loading by the sediments themselves may be an important cause of this subsidence. Offered in favor of this view is some of the evidence adduced by R. J. Russell and his associates of the Louisiana Geological Survey, but the scope of this paper is too limited to do full justice to those authorities. In this connection, the Gulf Coast geosyncline is illustrated and described with a reference to the views of Barton, for whom this feature is often called the "Barton geosyncline."

Considerable space is used in describing the special characteristics of structure, especially of faults and salt domes, whose development went on contemporaneously with sedimentation over long periods of time.

Throughout the article the point of view of a student is preserved since the paper results from an attempt by the writer to round out the work of a study group of which he was a member. It is suggested that this region affords exceptional data and facilities, perhaps the best in the world, for the study of clastic sedimentation. It is hoped that this article may direct attention to the Gulf Coast region for further study.

INTRODUCTION

This paper originated in the work of a study group of Corpus Christi geologists. The group learned quickly, and to its surprise, that the Gulf Coast region of Texas and Louisiana affords exceptionally full data for the study of clastic sedimentation. In fact, it is probably one of the best places in the world for such

[1] Manuscript received, February 19, 1945.

[2] Sun Oil Company. The writer wishes to thank the Sun Oil Company for permission to publish this article, and D. M. Collingwood, F. H. Lahee, Wallace Ralston, R. E. Rettger, R. J. Russell, and Paul Weaver for criticism and advice. He acknowledges also his obligation to the members of the Corpus Christi Geologists' Study Group who initiated the study on which the article is based. Their names are as follows: James L. Ballard, C. F. Barber, D. C. Barnett, R. M. Beatty, Carl F. Beilharz, Dale F. Benson, William H. Cardwell, J. T. Clark, W. R. Esgen, Dunbar A. Fisher, Guy F. Gierhart, A. M. Grant, J. M. Hancock, L. H. Haring, L. B. Herring, C. I. Jennings, Claude M. Langton, John H. Lock, W. A. Maley, Henry D. McCallum, O. G. McClain, L. H. Meltzer, P. A. Meyers, C. C. Miller, D. F. Newell, J. J. O'Brien, Frith C. Owens, E. D. Pressler, W. Armstrong Price, E. B. Rich, Sidney Schafer, R. B. Senseman, Fred P. Shayes, R. T. Short, Ira H. Stein, L. W. Storm, Rual B. Swiger, Reagan Tucker, Lawrence Vittrup, H. E. Voight, Lloyd G. West, Owen B. Wood.

Especial thanks are extended to W. Armstrong Price, with whom the writer has often discussed various problems of the Gulf Coast.

a study. This fact should be more widely understood, and its importance to the oil geologist more generally appreciated.

The notes which remained at the end of the course of study were very fragmentary, and, since the group as such was about to disband, there was no further opportunity to add to them. The notes, however, were entrusted to the present writer, with permission to round them out for presentation. He delivered a paper on the subject at the Association meeting in Houston in 1941, and has revised it somewhat in the unsettled times since then. It is offered now very much in its original form, as a study, or, perhaps more properly, as an invitation to study one of the most interesting sedimentary provinces to be found anywhere.

Basic Information

The sediments of this region are exposed in a broad belt along the coast in Texas and Louisiana; also they extend south along the coast of Mexico and eastward into Florida[3] (Fig. 1). The belt extends inland 200 or 300 miles and 75 or 100 miles out into the Gulf. Topographically the surface is a sloping plain, somewhat rolling on its inner edge where it abuts against the higher plain on the north. It flattens gradually toward the coast where, for the last 50 miles its slope is only a foot or two per mile. Outward from the shore the sea-bottom slopes 5 or 6 feet per mile for about 60 miles to approximately the 50-fathom line. Farther out it pitches at 50 or 60 feet per mile down to the Gulf floor at 2,000 fathoms.

The underlying beds (Fig. 2) crop out in bands which trend nearly parallel with the coast. In general, they are a set of truncated wedges lying on one another and thickening toward the sea. The dip of each bed also increases toward the sea, giving it a curved profile in cross section. At the outcrop, the older beds dip about 150 feet per mile but each succeeding younger bed is flatter, the last of the series being the stratum which is now accumulating parallel with the sea-bottom.

A continual subsidence of the seaward part of the accumulation appears to have produced the dip of the beds and their curved profiles, and to have broken them by tension faults which trend parallel with the coast. In central Texas, the faults farthest inland constitute the Balcones fault zone. At Austin, for example, the aggregate displacement of several faults is approximately 800 feet, down toward the southeast; and the rolling black lands of the Upper Cretaceous abut against the hills which merge into the plains country of the Lower Cretaceous on the northwest. This fault zone is also approximately at the southeast edge of

[3] F. B. Plummer, "Cenozoic Systems in Texas," in "Geology of Texas, Vol. 1, Pt. 3," *Univ. Texas Bur. Econ. Geol. Bull. 3232* (1932), pp. 519–818.

Geological bulletins of Louisiana Department of Conservation on various southern provinces of Louisiana.

Henry V. Howe, "Review of Tertiary Stratigraphy of Louisiana," *Gulf Coast Oil Fields*, Amer. Assoc. Petrol. Geol. (1936); *ibid.*, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 6 (June, 1933).

Alexander Deussen, "Geology of the Coastal Plain of Texas West of Brazos River, *U. S. Geol. Survey Prof. Paper 126* (1924).

the Llanoria geosyncline which, in early and middle Paleozoic time, lay between Llanoria on the southeast and an interior mass on the northwest. This old line, apparently one of weakness, follows in general the inland boundary of the

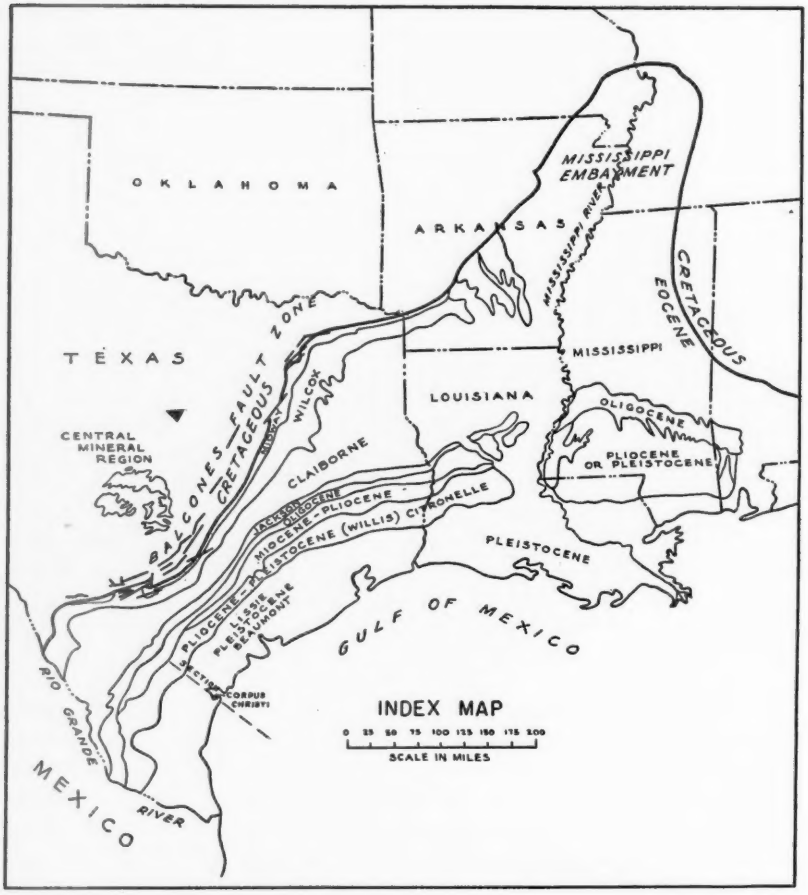


FIG. 1.—Area under discussion, shown in somewhat diagrammatic manner. Traced from reduced copy of *Geological Map of the United States* (United States Geological Survey).

coastal province. With the change in topography along it, this zone continues northeast and southwest but becomes less pronounced in southern Texas and in northeast Texas and Arkansas.

Most of the other faults traversing the coastal block are also downthrown

toward the Gulf; but some, like those of the Luling-Mexia trend, are downthrown in the opposite direction and have grabens northwest of them.

Other important structural features of the province are the salt domes of Louisiana, southeast Texas, and Mississippi.

The clastic sedimentation followed retreat of the Cretaceous seas from interior North America. The sediments differ fundamentally from those which

CORRELATION OF TERTIARY FORMATIONS

		PENROSE	KENNEDY	KENNEDY	DUMBLE	DEUSSEN	LOUISIANA	PRESENT
TERTIARY	PLIOCENE			FLEMING	FLEMING	LAGARTO LAPARA	FLEMING	FLEMING — LAGARTO
	MIOCENE					OAKVILLE		OAKVILLE
	OLIGOCENE?				CATAHOULA	CATAHOULA	CATAHOULA	CATAHOULA
		FAYETTE			JACKSON (MANNING, CADDELL, WELLBORN)	FRIO FAYETTE	JACKSON	JACKSON
	EOCENE	CLAIBORNE GROUP — FAYETTE		LUFKIN OR ANGELINA	YEGUA / NACOGDOCHES	YEGUA	COCKFIELD	YEGUA
		SABINE RIVER	MARINE		COOK MOUNTAIN	COOK MOUNTAIN	ST. MAURICE, JONESBORO, MINDEN, SPARTA	COOK MOUNTAIN (SALINE BAYOU, MILAMS, CROCKETT, SPARTA)
					MOUNT SELMAN	MOUNT SELMAN	CANE RIVER	MOUNT SELMAN (WECHES, QUEEN CITY, REKLAW, CARRIZO)
					UNCONFORMITY			
		TIMBER BELT BED	LIGNITE	QUEEN CITY / WILCOX	WILCOX	MIL-COX (CARRIZO, INDIO)	WILCOX	WILCOX
				MIDWAY	MIDWAY	MIDWAY	MIDWAY	MIDWAY

FROM LOWER CLAIBORNE OF EAST TEXAS
BY E. A. WENDLANDT AND G. MOSES KNEBEL
A.A.P.G. BULLETIN - VOL. 13 - P. 1351

FIG. 2.—Tabulation showing various revisions of nomenclature of Gulf Coast Tertiary. "Present" column shows names in use when tabulation was published, in October, 1929. There has not been much revision since then. Pleistocene not included.

accumulated while the Cretaceous seas were advancing upon the continent. The Cretaceous of Texas is prevailingly calcareous, heavy limestones being a common feature of the earlier formations, and even the later Cretaceous beds are ordinarily calcareous enough to be classed as marls. The latest Cretaceous of Texas, the Navarro, is still a marl or marly shale. Above it is a disconformity which is generally thought to represent a decided retreat of the sea. The next bed above the disconformity and, assigned generally to the Eocene, is the Midway.[4] It is also ordinarily somewhat marly; in places some limestone is developed in its

[4] There is some dissent from this opinion: see Gayle Scott, "Age of the Midway Group," *Bull. Geol. Soc. America*, Vol. 45 (1934), pp. 1111–58.

basal part; but, upward, the Midway grades into a more sandy formation, the Wilcox.

The faunal break from Navarro to Midway is usually considered to be rather striking, with a Cretaceous fauna below and an assemblage with generally Eocene affinities above, but lithologically the Midway is like a transition bed. The Wilcox into which it grades above, is more typical of the clastic sediments which constitute the Tertiary of this province. They seem to represent the detritus from newly uplifted regions, some of them close at hand, others as far away as the Rocky Mountains and the Great Plains. In them, perhaps, it would be possible to read the history of recurrent uplifts, which have started the material for sediment moving toward the coast, and of quiescent periods when there was less wastage by erosion and less material arriving at the coast.

The ultimate result has been to extend the land gulfward, but there have been many recessions of the shore line, many advances and retreats of the sea, which were due probably, in part, to rise and fall of sea-level, in part to change in the rate of sediment accumulation. Near-shore facies characterize the updip portions of nearly all the deposits. Some of this material was deposited above tide-level, some of it just below. Downdip, as encountered in wells, most beds become marine, although of a shallow-marine type. Wells reveal the presence of some beds which were overlapped and do not crop out.

At the beginning of the Tertiary, the shore lay well inland from the present Cretaceous-Eocene contact (Fig. 1). The Mississippi River probably did not supply as great a proportion of the sediment as it does to-day, while the ancestral Rio Grande or Pecos and other rivers supplied more. Probably some important river flowed into the East Texas embayment. From this beginning the sediments seem to have been deposited seaward nearly as they are being deposited now. Therefore, a study of what is now going on may be the best approach to an understanding of the older sediments.

Sediments of Recent and Pleistocene

Recent and Late Pleistocene sediments along the Gulf Coast, according to their origin, may be subdivided as follows.

1. Deposits near the river mouths, mainly deltaic
2. Near-shore deposits
3. Deposits off shore on the continental shelf

1. DELTAIC DEPOSITS

The Gulf Coast region includes one of the great deltas of the world, that of the Mississippi. Much has been written about it, perhaps the fullest accounts being those of the Louisiana Geological Survey,[5] by H. V. Howe, R. J. Russell, R. D. Russell, and H. N. Fisk.

[5] Richard Joel Russell and R. Dana Russell, "Mississippi River Delta Sedimentation," *Recent Marine Sediments*, Amer. Assoc. Petrol. Geol. (1939), p. 153.

The structure of this delta, as described by these writers, is different from what is commonly known as delta structure. Yet the Mississippi type of structure seems to be that of large deltas in general.

The Mississippi delta is being deposited by distributary branching streams which build out natural levees onto a platform already prepared by wave and current action. The levees sink under their own weight into the unconsolidated mass beneath, carrying down with them the interfingered areas which are occupied by swamps, lagoons, and arms of the sea. Crevasses form in time of flood and the streams shift about, filling first one area and then another, and eventually returning to the previous ones when they have subsided far enough. The history of these changes in southern Louisiana can be read on the surface by the old river channels and by remnants of the natural levees. The repetition, of deposits embodying such changes has been proved to a depth of hundreds, even thousands of feet, by bore holes. Thick lenses or pockets of sediments may accumulate where a river continues depositing for a long time in one place. One of these pockets, 3,000 feet deep, is believed to exist in the region of New Orleans where deposition has been concentrated during the past 20,000 or 30,000 years, in Recent time.[6]

The type of structure with which the term "delta structure" has generally been associated, was described in detail by G. K. Gilbert.[7] Along the shores of the ancient Lake Bonneville in Utah, are many deltas of small streams which emptied into the comparatively still waters of the lake. Each of them built out a gently sloping platform with a front plunging steeply to the lake bottom.

These deltas, left "high and dry" when the lake dried up, are exposed for detailed study, and they served as the type for Gilbert's classical description. The structure which he describes with top-sets, fore-sets, and bottom-sets has been accepted as the true delta type.

Such structure develops where streams encounter still water, as in lakes or ponds. As small deltas, and on a still smaller scale, as cross-bedding, this structure may be observed in nearly any shallow-water or terrigenous deposit. The Mississippi type of delta is, however, the marine type which is quite distinct from that described by Gilbert. Such deltas are formed where wave action and shore currents are strong and where a great amount of material has to be deposited in comparatively shallow water. See Figure 3 for comparison of the two types of delta structure.

Richard Joel Russell and Henry V. Howe, "Lower Mississippi Delta," *Louisiana Geol. Survey Bull. 8* (1936), p. 440.

H. N. Fisk, "Summary of the Geology of the Lower Alluvial Valley of the Mississippi River," Mimeographed. *War Dept., Corps of Engineers, U. S. Army, Miss. River Com.* Appendix II, Review of Project for Improvement of Mississippi River. Published at U. S. Waterway's Experiment Station, Vicksburg, Mississippi (1943). 49 pp., 15 pls., 2 figs.

[6] John W. Frink, "Subsurface Pleistocene of Louisiana," in "The Sand and Gravel Deposits of Louisiana," *Louisiana Geol. Survey Bull. 19* (1941).

[7] Grove Karl Gilbert, "Lake Bonneville," *U. S. Geol. Survey Mon. 1* (1890). XX and 438 pp., 51 pls., 1 map.

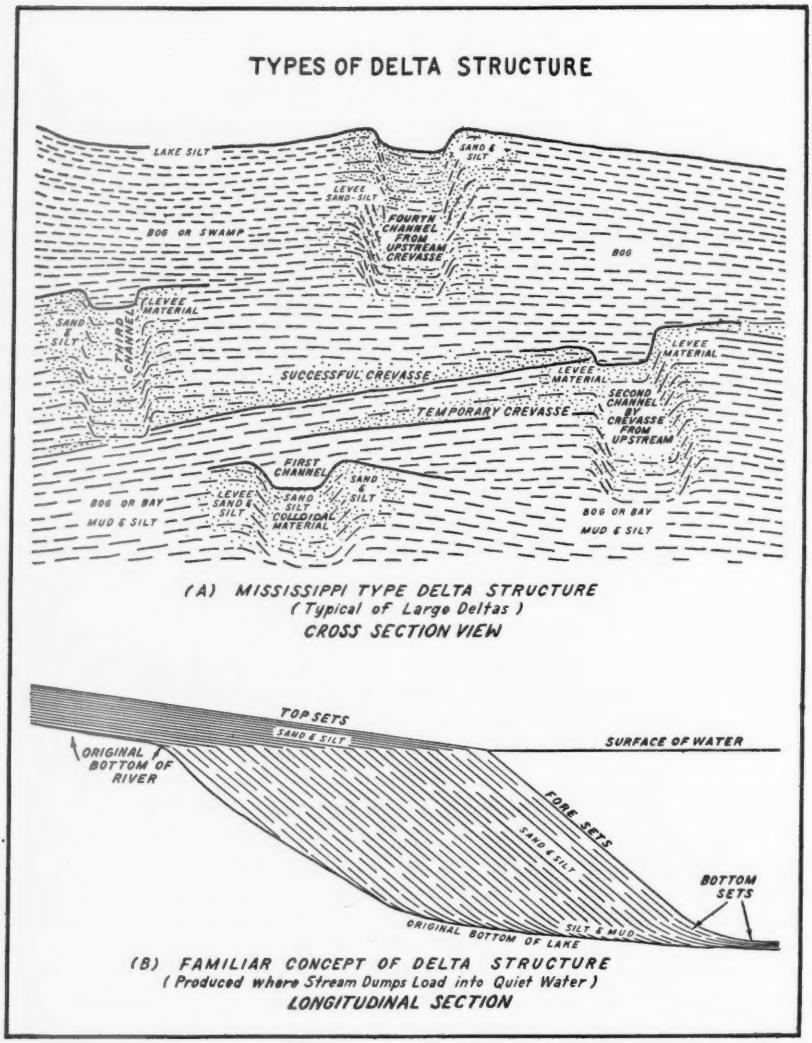


FIG. 3.—Diagrammatic sections showing two contrasting types of delta structure. For either type, the structure is commonly more complicated than diagram shows. Any delta of considerable size ordinarily combines features of both types.

In spite of its distinct features, it has been suggested that on a large scale, the Mississippi delta still conforms with the Gilbert concept.[8] In this view, the complexly deposited sediments of the visible delta would correspond with the top-sets, those dumped over the front of the continental shelf would be the fore-sets, and what fine sediments there may be on the Gulf floor beyond the toe of the shelf would be the bottom-sets. But the top-set region, in this case, is not a series of layers, but a complex mass of deposits with little or no semblance of layers; and the slope of the fore-sets is very slight.

2. NEAR-SHORE DEPOSITS

The Rio Grande, like the Mississippi, is forming a delta though on a smaller scale.[9] For the other rivers of the Gulf Coast, the formation of deltas has apparently been interrupted until they have completed the filling of old bays and estuaries.

More characteristic deposits for this near-shore region between the Rio Grande and the Mississippi are those of the Pleistocene, which is exposed in a belt 50 to 75 miles wide fronting on the shore. This coastal strip of land was regarded for a long time as a region where flat, off-shore deposits had been exposed recently by a retreat of the sea. Soil studies, however, and careful mapping have shown that these deposits are more like those now forming in the Mississippi delta.

The surface near the coast shows a complicated pattern of old natural levees which are easily recognized by the sandy material in them and by their elevation above the adjacent terrane. The soil map of Harris County, Texas, for instance, which is colored to show distribution of the soil types, reveals very clearly the wanderings of the various distributary streams of an old delta of the Brazos River.[10] Many oil geologists have had occasion to study similar levees of Pleistocene distributaries of the Colorado River. Deposits of this deltaic type extend along the coast of Texas and Louisiana. They seem to have been formed near the mouths of rivers, first in one place, then another, as the rivers shifted. Deposits of the several rivers appear to coalesce with one another at the sides. There are signs also of interfingering of marine deposits, as in the Mississippi delta; thus, the sea had a part in filling the interdelta lagoons. However, the

[8] A. C. Lawson, "Mississippi Delta—A Study in Isostasy," *Bull. Geol. Soc. America*, Vol. 53, No. 8 (1942), p. 1235.
"This brief account of the small delta, based on Gilbert's classic work on the shore features of Lake Bonneville, serves equally well for the structure of the great deltas of the earth."

[9] W. Armstrong Price, paper in preparation.
———, "Pleistocene Physiography of the Northwestern Gulf of Mexico Coastal Plain" (abstract), *Proc. Geol. Soc. America for 1937* (1938), p. 104.
———, "Physiographic Mapping of Quaternary Formations in Rio Grande Delta" (abstract), *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 12 (December, 1939), pp. 1875–76.

[10] D. C. Barton, "Deltaic Coastal Plain of Southeastern Texas," *Bull. Geol. Soc. America*, Vol. 41 (1930), pp. 359–82.

remnants of delta topography cover most of the area. The late D. C. Barton devoted much of his life to a study of this region. He described it as an excellent example of a type of physiographic province for which he proposed the name, "Deltaic Coastal Plain."[11] The Quaternary deposit on whose surface the delta features are still preserved and recognizable is known as the "Montgomery" or "Prairie" in Louisiana[12] and the Beaumont[13] in Texas. It is similar in all respects to the Recent. A pocket of Mississippi sediments of this age is said to have accumulated west of New Orleans[14] near the one mentioned under "Recent" deposits. The work of the Mississippi is recognizable on the surface in these late Pleistocene beds as far west as eastern Texas. The Beaumont is about 50 miles wide and its average slope seaward is about one foot per mile. In it are exposed clays, sands, and sandy clays.

A parallel and more sandy belt, known in Texas as the Lissie, occurs next inland from the Beaumont. Its surface slopes seaward 3 or 4 feet per mile. It has been somewhat eroded, and the old surface delta features, if they ever existed, can no longer be recognized. The original gradient of the Lissie was probably steeper than that of the Beaumont, but it is apparently deltaic in character and is included in the deltaic coastal plain. Inland from the Lissie is another formation, still more sandy but otherwise similar. Its surface slope is about 8 feet per mile coastward and it has been considerably eroded. East of the Brazos this is the formation to which the name "Willis" was given by John Doering.[15] He considered it as Pleistocene. Southwest of the Brazos, conditions change, apparently with a change to drier climate. Calcareous phases come in or new formations are present. There is difference of opinion about the exact relationships of this inner belt through southern Texas, although Beaumont and Lissie can easily be recognized to the Rio Grande and beyond.

Although these Pleistocene beds are easily distinguishable on the surface, they are hard to separate in the subsurface. The United States Geological Survey, in conjunction with the Texas Board of Water Engineers, has tried intensively and without much success to make subsurface correlations of these beds.[16]

Many of the sands of these deposits intercommunicate for they act as one reservoir. The Houston region depends on them for its water supply. Water is

[11] Donald C. Barton, *op. cit.*

[12] Harold Norman Fisk, "Geology of Grant and LaSalle Parishes," *Louisiana Geol. Survey Bull. 10* (1938). 246 pp., 23 pls., 16 figs.

[13] Alexander Deussen, *op. cit.*

[14] John W. Frink, *op. cit.*

[15] John Doering, "Post-Fleming Surface Formation of Coastal Southeast Texas and South Louisiana," *Gulf Coast Oil Fields*, Amer. Assoc. Petrol. Geol. (1936), pp. 432–69; also *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 5 (May, 1935), pp. 651–88.

[16] Nicholas A. Rose, "Ground Water and Relations of Geology to Its Occurrence in Houston District, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 8 (August, 1943), pp. 1081–1101.

pumped from a dozen different levels and a study of the cone of water depression proves the connection among the sands.

The effect of heavy pumping in any part of this area upon the water level or the output from near-by or from distant wells commonly shows that communication up and down the dip in these sands is much more direct than it is along the strike.[17] This probably means that the best communication is in the general direction in which the wandering ancient streams flowed while they were depositing these sediments. On the other hand the easiest communications for fluids may be parallel with the shore in deposits whose grain was determined by wave and current action. Perhaps a study of such differences in sand structure may help explain the anomalies of pressure change in some oil or gas fields.

3. DEPOSITS OFF SHORE ON CONTINENTAL SHELF

Along shore there is generally a sandy beach, seaward from which there is a lagoon 3 or 4 miles wide. Next, in many places, there is a barrier island of sand a mile or several miles wide with a fore-beach of sand extending a mile or more into the Gulf. Beyond this, conditions differ at different localities. The so-called normal sequence of sand close to shore, becoming more and more shaly seaward, does not everywhere prevail.

Some careful studies, which are more or less confidential, have been carried on along this shore. The results are not ready for publication in full, but the following statements are authorized. Not far from Corpus Christi a series of samples was collected. Beyond a zone of rather fine material near shore, there is a narrow belt of sands with an average grain diameter of 0.21 millimeter parallel with the shore and about 12 miles distant from it. Beyond that the grain size decreases again until it averages about 0.03 mm. about 20 miles from shore. It increases to an average of 0.18 mm. (a fair sand) at 30 miles from shore. From there out to about 40 miles from shore the grain size remains about the same. Beyond 40 miles from shore the grain of the sediments becomes finer and finer.

It may be significant that these sandy belts correspond in their positions almost exactly with those of currents which are shown on the United States Coast and Geodetic Pilot Charts. The silt is in the slack-water region between the currents. The current nearest the shore flows southwest and, as shown on the monthly charts, is always in about the same position. The outer current flows northeast and shifts considerably with the seasons. This shifting may account for the width of the sandy belt about 35 miles from shore.

Current velocities at the surface vary from 0.5 mile to 1.5 miles per hour. This, with the help of the waves, is enough to move fine sand. Little is known of the current velocities at depth. The off-shore current is the stronger, but depth to bottom is greater. Whether these sandy belts are present all along the shore and whether their positions correspond with those of the currents may be known later when investigation can be continued after the war.

[17] Nicholas A. Rose, oral communication.

Bottom samples taken in a belt across the continental shelf from a point just south of Corpus Christi show a residue of fine sand in the washed samples. Beyond a water depth of 200 to 250 feet there is little sand in the residues, the coarse material being mainly fragile shells. Evidently current and wave action are hardly present at this depth and sand in quantity was not carried there.

As it stands, the evidence is for belts of sand deposition alternating with belts of mud deposition, with some sand nearly, if not quite, out to the edge of the continental shelf 50 to 100 miles from shore. It has generally been supposed that sand is deposited only close to shore, and wide belts of sand have been explained by shore-line migration. Distribution of sand and mud now being deposited along the Gulf shore indicates that it is not necessary to call upon shore-line migration to explain occurrence and recurrence of sand over a belt as much as 40 or 50 miles wide along a shore.

Special Features of Pleistocene

While it may be said that the Pleistocene and Recent of the Gulf Coast are only the latest members of a series which runs back to the Eocene, still, in detail at least, they differ from the older beds. They constitute a little series of their own, and it may be well to point out some of their peculiarities before attempting to make inferences from them about the older beds.

Perhaps the simplest explanation of the special features in the deposits of this series is to be found in their relationship to conditions prevailing during the Ice age. It is recognized that the accumulations and recessions of the ice were associated, through cause and effect, with many changes of climate, topography, and stream drainage, with shifts in areas of deposition, and with changes in material deposited even in areas at considerable distances from the ice sheets. Where the ice accumulated, it changed even the shape of the earth by pressing down regions where the ice was thick. Almost any modern text book on geology describes these effects.[18] They are obvious enough in North-Temperate latitudes, less obvious in regions farther south. It is generally recognized, however, that climatic belts such as the Northern Rain Belt was shifted south as the ice accumulated and north again when it melted.

Glacial changes in the drainage areas of the Ohio, the Missouri, and the Upper Mississippi, must greatly have affected the amount and character of the sediments delivered by the Mississippi at its mouth, and changes of climate probably affected to a less degree the load carried by other rivers emptying into the Gulf. Some of these changes are no doubt recorded, clearly or faintly, in the Gulf Coast Pleistocene deposits.

As to other Ice-age changes, some of them of world-wide scope, there is still some controversy. One of them, however, has also received text-book recogni-

[18] For example: see Longwell, Knopf, and Flint, *Physical Geology*, pp. 162–72; also Schuchert and Dunbar, *Historical Geology*, pp. 434–39.

tion.[19] The change referred to is the fall and rise of sea-level, which is said to have occurred with each withdrawal of water from the sea to form the ice caps and its restoration when the ice melted.[20]

Dissent from this view is now probably the exception among leading students of the Pleistocene.[21]

Gulf Coast opinion seems generally to endorse this theory of glacial-control oscillation of sea-level. The Louisiana State geologists, in their studies of the Mississippi, have had occasion to write a number of papers in which this theory forms part of the basis for their conclusions.[22]

As a corollary of this theory, each rise and fall of sea-level would produce an advance and retreat of the sea and a wedge of sediments extending landward. The Pleistocene series of beds would consist of these recurrent wedges. Further development of this theory as applied to the Gulf Coast Pleistocene is as follows.

For the amount of rise and fall of sea-level, 250 to 300 feet is a figure which has been tentatively accepted by a number of writers on the subject.[23] Since the present is a period of ice retreat it can be assumed that it is one of high sea-level, and if 300 feet was the amount of rise, recent deposition began when sea-level was about 300 feet lower than it is now. The shore then would have been out somewhere near the edge of the continental shelf where the depth of water is now, in fact, about 50 fathoms, or 300 feet. In each glacial period, the sea is supposed to have retreated to approximately this edge. Beyond this break in slope, the deposition was continuous and deposits are thick. Each deposit, however, would thin out gradually shoreward as the ice melted and the sea advanced to its high-level position. Thus, the Pleistocene beds exposed on shore are only the thin updip edges of the formations.

The fact that even these insignificant edges are exposed, requires an explana-

[19] Longwell, Knopf, and Flint, *op. cit.*, p. 172.
Schuchert and Dunbar, *op. cit.*, p. 434.

[20] Some of the earlier references are:
Ernst Antevs, "The Last Glaciation," *Amer. Geogr. Soc. Research Ser.*, Vol. 17 (1928). 292 pp.
R. A. Daly, "Swinging Sea Level of the Ice Age," *Bull. Geol. Soc. America*, Vol. 40 (1929), pp. 721–34.

[21] A reference to the literature of regions other than the Gulf Coast: Paul MacClintock and Horace G. Richards, "Correlation of Late Pleistocene Marine and Glacial Deposits of New Jersey and New York," *Bull. Geol. Soc. America*, Vol. 47 (1936), pp. 289–338; 2 pls., 5 figs.

[22] H. N. Fisk, "Summary of the Geology of the Lower Alluvial Valley of the Mississippi River," *op. cit.* Former sea-levels at 200 to 300 feet, Pl. 9. Glacial-control oscillations *et cetera* maintained. Subsurface structure of Mississippi valley and delta based on 10,000 bore holes with full data on position of rock floor and old sea-level.
———, "Geology of Grant and LaSalle Parishes," *op. cit.* Eustatic, glacial-control oscillations of sea-level given on pp. 67–75.
Richard Joel Russell, "Quaternary History of Louisiana," *Bull. Geol. Soc. America*, Vol. 51 (1940), pp. 1199–1234; 4 figs. Eustatic glacial-control oscillations of sea-level. Quantatitive estimates of Daly, Dubois, Antevs, of approximately 300 feet for maximum glaciation, cited as in line with Louisiana estimates, pp. 1219–23.

[23] Longwell, Knopf, and Flint, *op. cit.*, p. 172.
Schuchert and Dunbar, *op. cit.*, p. 434.

tion. For why did not the sea obliterate all traces of the next older edge each time it reached a high-level stage? The explanation offered, by exponents of the theory under discussion, is that uplift of the edge of the older formation had occurred in the meantime and therefore its edge was not covered by the advancing sea. The whole off-shore belt is postulated to be sinking as the sediments accumulate, while a compensating rise is postulated in the adjacent inland region. As an example: the Lissie surface probably had originally a slope of only a foot or two per mile and ended landward against the old Willis surface which had already been slightly tilted. As the shore receded to the edge of the continental shelf and then returned, the weight of the constantly accumulating sediments depressed the off-shore belt while, in compensation, the near-shore land was slightly elevated. Thus, the seaward slope of the Lissie was increased and the deltaic Beaumont deposits have their landward edge against the sloping Lissie surface.

This progressive rise of the land and seaward tilting of the zone of deposition, with recurrent advance and retreat of the sea, would account for conditions which are known to be present. The seaward slope or surface gradient on each older Pleistocene deposit is greater than that of the one next younger. For the Beaumont, it is 1 or 2 feet per mile; for the Lissie, 4 or 5 feet per mile; for the Willis, about 8 feet per mile. The change from one slope to another is not gradual but is marked by a distinct break and each of these breaks maintains a nearly constant level, that between Beaumont and Lissie being about 60 feet above the present sea-level and that between Lissie and Willis about 170 feet above sea-level.[24] At this latter break there is something like a well defined scarp, in places, where there is a rather sudden rise of about 30 feet from an elevation of 170 feet to that of 200 feet. This is called the Hockley scarp. These breaks have been considered as old shore lines. More likely, they mark the inner edges of deltaic plains. A full knowledge of the nature of this Pleistocene surface is valuable to an oil geologist, as any slight departure from the normal surface may mean presence of a salt dome or a fault with which an oil accumulation may be associated.

Conditions apparently in harmony with the general theory are found along the rivers of this region. Whenever the sea-level was low, the rivers had to cut gorges to adjust their gradients. There are signs of these gorges and adjustments. Each Pleistocene deposit, the Beaumont and Lissie especially, extends as a terrace up each of the main rivers.[25] Those of the younger formations have flatter gradients than the older ones. There are, however, intermediate terraces

[24] John Doering, *op. cit.*
Statement also supported by studies of the present writer.

[25] H. N. Fisk, "Geology of Grant and LaSalle Parishes," *op. cit.*, p. 246.
H. V. Howe and C. K. Moresi, "Geology of Lafayette and St. Martin Parishes," *Louisiana Geol. Survey Bull. 3* (1933), p. 237.
Albert W. Weeks, "Lissie, Reynosa, and Upland Terrace Deposits of Coastal Plain of Texas between Brazos River and Rio Grande," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 5 (May, 1933), p. 453.

whose presence requires an explanation. Where the Mississippi River gorge comes out of the Pliocene deposits, it is about 300 feet deep. Recent deposits have filled this gorge and extend as a terrace up its valley. They also extend far out to sea as the present delta. The Rio Grande has also filled its latest Pleistocene gorge and is building a delta. The other rivers, Brazos, Trinity, *et cetera*, it appears, have yet to fill the estuaries and bays at the mouths of their old gorges before they can resume their regular work of advancing the deltaic coastal plain. This would explain the "drowned" condition of most of the Texas shore, for which few or no other explanations have been offered.

This is a very brief outline of the explanation of Gulf Coast Pleistocene conditions, by means of the glacial-control, sea-level oscillation theory. The reader may find it all in the publications cited. Deficiencies will no doubt be found in it. Many of its details and perhaps some of its main features will have to be revised, but it is believed that much of it will stand. It gains more and more adherents, the most prominent of whom are the Louisiana geologists, who, of all geologists, have studied the Mississippi and its Pleistocene sediments most intensively.

At this point the subject of submarine canyons and the tremendous fall and rise of sea-level, which seems necessary to account for some of them, naturally arises. Such canyons are found in many parts of the world, apparently extending the valleys of rivers across the continental shelf.[26] It seems that some sign of such valleys might be found off the Gulf Coast. Irregularities off shore in the Gulf have indeed been found and have been interpreted as remnants of these old canyons,[27] but the inferences are not at all clear. The presence of a canyon-like depression west of the Mississippi delta is well known but opinions differ greatly about it.

Better charts than those we have now may eventually reveal unmistakable evidence of canyons. Perhaps such canyons were formed and afterwards filled. The lack of canyons *here* may be included among the many things still to be explained about these remarkable features.

Not all that has been said about Recent and Pleistocene sediments will apply to the preceding Tertiary beds, but much of it will apply rather closely and permit inferences to be made about probable conditions in the older beds. In discussing the individual Tertiary beds or general features about them, references are made again to the Pleistocene.

[26] W. H. Bucher, "Submarine Valleys and Related Geologic Problems of the North Atlantic," *Bull. Geol. Soc. America*, Vol. 51, No. 4 (April, 1940), pp. 489–511.
F. P. Shepard, "Hypothetical Submarine Valleys," *ibid.*, Vol. 52, No. 12 (December, 1941), p. 1934.
A. C. Veatch and Paul A. Smith, "The Surface and Subsurface Exploration of Continental Borders; Mapping of the Submarine Valleys of the Atlantic," *Trans. Amer. Geophys. Union*, 21st Annual Meeting, Pt. 3A (1940), p. 786.

[27] Edward Hull (and J. W. W. Spencer), *Monograph on the Sub-oceanic Physiography of the North Atlantic Ocean;* chapter by Spencer on "Physical Features off the Coast of North America and the West Indian Islands." 41 pp., maps. London.

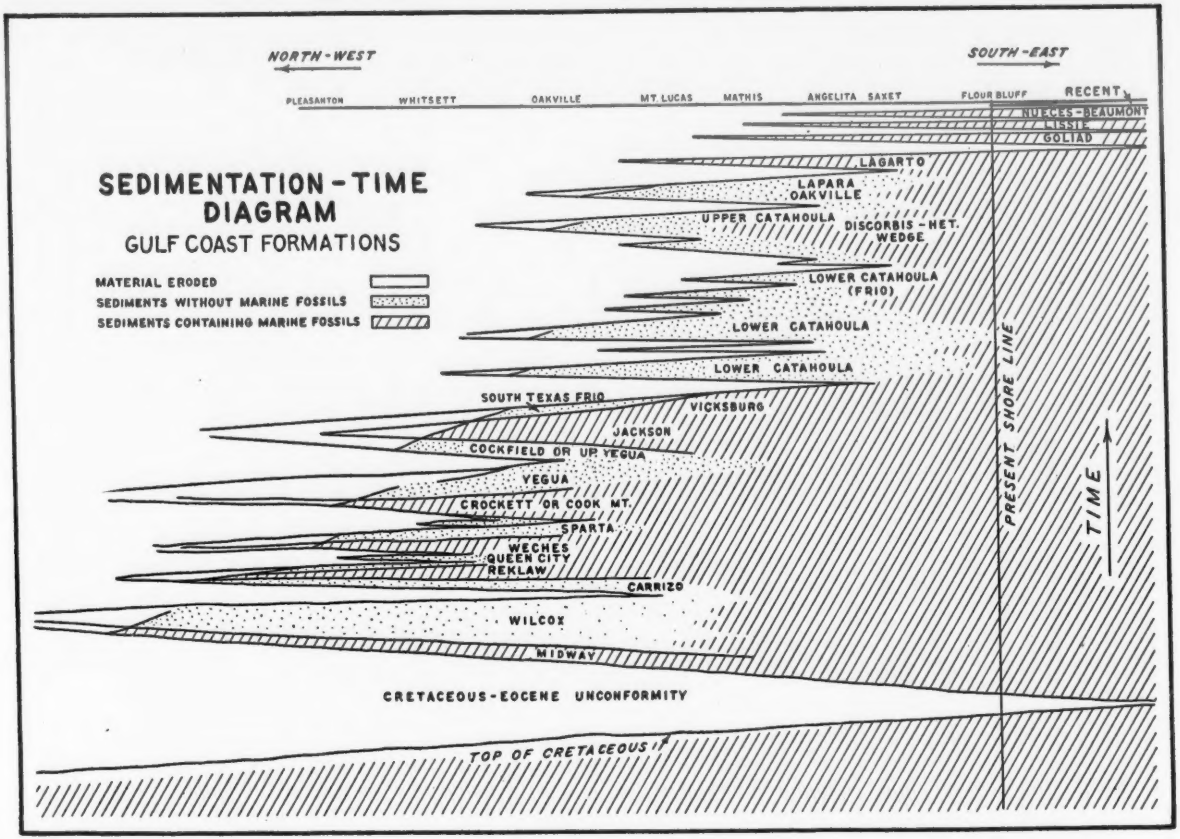


FIG. 4.—Diagram showing that, in Tertiary time, sedimentation went on continuously outside a position probably somewhere near present shore line. From this position, advances of sea brought with them tongues of sediments. Retreats of sea exposed these deposits to erosion. Part of tip of each tongue or wedge was completely removed by erosion and is now missing from section. During Pleistocene, and possibly later Pliocene, sedimentation has been interrupted sometimes beyond present shore line.

Sediments Older than Pleistocene

1. Role of subsidence in accumulation

Under Recent and Pleistocene, there were described: (a) the sinking of natural levees and other delta features into the unconsolidated material beneath: (b) more extensive sinking of heavily sedimented delta areas into deep pockets, as near New Orleans; and (c) the postulated sinking of accumulated deposits along a shore and a compensating rise of the adjacent shore belt.

Sinking of the (a) type is a matter of detail and, though present in the updip or deltaic parts of the older beds, seems to have no great significance.

Thick lenses of formation which are shown on isopach maps of some of the Gulf Coast formations are suggestive of pockets of the (b) type. It is difficult to see how such lenses could accumulate without subsidence to make room for them.

Subsidence of the (c) type may be considered as the beginning or faint near-surface expression of such subsidence as is discussed later under the heading of "Regional Structure and Development of Geosyncline."

Subsidence on a far greater scale has affected the deeper beds and the accumulation as a whole. Beds containing shallow-water fossils are found in the deepest Gulf Coast wells at 14,000 feet below sea-level. This is discussed more fully under "Structure" and "Development of Geosyncline."

2. Significance of frequent changes of sea-level

The Tertiary is not characterized by a glacial-controlled fall and rise of sea-level. But there is evidence, in its stratigraphy, of many incursions and retreats of the sea. As in the Pleistocene, there was, beyond the farthest retreat of the sea, a position where the deposition of sediments was continuous. This may have been near the present shoreline toward the end of the Tertiary, but farther inland for the older beds. From this position, advances of the sea brought wedges of sediments inland.

Figure 4 is a combined time scale and sedimentation diagram. It shows the continuous sedimentation downdip, the tongues of formations extending landward, and the unconformities between them. It shows also the over-all advance seaward of the mass of sediments. Its purpose is chiefly diagrammatic and scarcely any student of Gulf Coast stratigraphy will agree with it in all details.

Figure 5 is a familiar diagram of the same sort by F. B. Plummer,[28] modified from an older one by H. B. Stenzel.

Many readers will recall such diagrams also in connection with a paper by Phillip F. Martyn, describing the Gulf Coast sediments in relation to advances and retreats of the sea. He read the paper first at a meeting of the Houston Geological Society and was asked to repeat it in San Antonio, Corpus Christi,

[28] F. B. Plummer, *Geology of Texas, op. cit.*, p. 528.

possibly later Pliocene, sedimentation has been interrupted sometimes beyond present shore line.

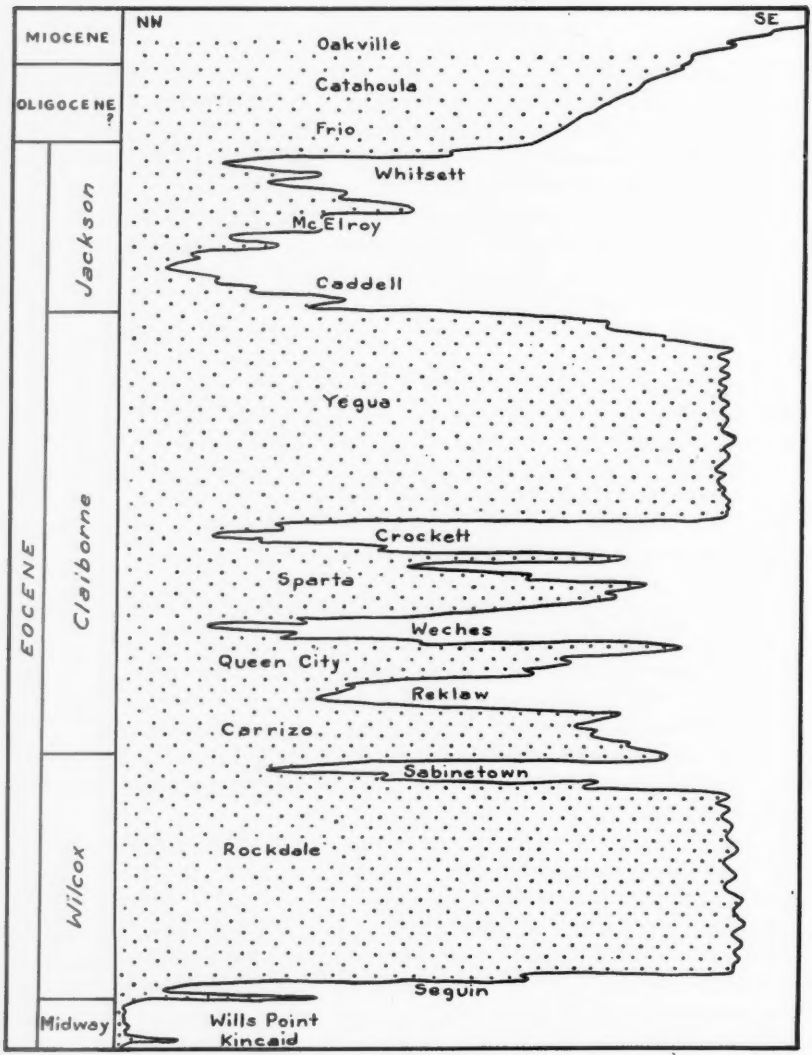


FIG. 5.—Diagrammatic representation of changes in strand lines during Cenozoic era. Stippled part represents land; blank part, sea. Extension of blank areas northwest shows advance of seas. Extension of stippled areas southeast indicates retreat of seas. Modified from diagram by H. B. Stenzel, "Geology of Texas, Vol. I," *Univ. Texas Bull. 3232* (August, 1932), p. 528.

and at group meetings of geologists elsewhere. This was in 1939 and 1940. Unfortunately it has not appeared in print.

As with the Pleistocene and Recent, the updip parts of the Tertiary wedges, as now exposed, are largely terrigenous, or they belong to the belt where deposition is partly above and partly below tide-level.[29] Much cross-bedding and delta structure of the Gilbert type are in evidence; also, much that is nearly related to delta structure of the Mississippi type or of a deltaic coastal plain: Wilcox, Yegua, Catahoula, as examples. Sediments of this character are commonly encountered in wells far downdip from the outcrop, thus showing progressive subsidence of such subaerial, or partly subaerial, deposits or their original distribution over a wide belt. This material everywhere grades into shallow-marine sediment. With some of the beds, erosion has exposed marine sediments at the outcrop, but, in the case of most of the formations, at some place on the outcrop some of the subaerial deposits remain.

3. SPECIAL CHARACTERISTICS OF FORMATIONS

The Midway extends far inland as a rather thin wedge. It seems to represent a period of slow marine deposition.

The Wilcox, on the other hand, seems generally to have built out quickly, following or driving back the Midway sea.[30] On the outcrop it is mainly terrigenous. There it shows quick changes of facies from chocolate shale full of leaf impressions to thick beds of sand, which generally contain silicified wood, some of the pieces representing entire tree trunks. The silica probably came from volcanic ash in the sands. Commonly there are large calcareous concretions in the sand, and some near-shore fossil shells. Much of it is cross-bedded and contains small deltas of the Gilbert type. There are also many sudden changes horizontally from prevailingly sandy to prevailingly shaly sedimentation, and many other evidences of the work of wandering streams. Downdip, as shown in deep wells, it becomes marine and contains fossils closely related to those of the Midway. Some of the marine sands contain oil. The deepest wells show that sand was giving place to shale as the sedimentation progressed seaward.

Some geologists attribute the Carrizo to an advancing sea; others postulate a retreating sea. An unconformity of some sort is generally recognized between Wilcox and Carrizo.

The Reklaw, Queen City, Weches, Sparta, and Crockett lying above the Carrizo represent a period when the sea remained well inland, with minor advances and retreats.

Then the Yegua, overlying the Crockett, was built out in the same rapid way as the Wilcox. In many ways, it is very similar to the Wilcox with leaf impressions, fossil wood, cross-bedding, and small deltas. Downdip it becomes marine

[29] H. B. Stenzel.

[30] F. B. Plummer, *Geology of Texas*, p. 571.

and there it begins to contain oil, as at Conroe, while farther downdip the upper sands begin to play out, but deeper sands come in and produce oil around salt domes, for example, Humble and Hull. The whole marine sand belt is about 35 miles wide. Cockfield, a name by which many geologists have known the Yegua, is still commonly applied to the upper part of it. Some geologists separate it from the lower Yegua by an unconformity, as shown in Figure 4.

The sea was inland during Jackson time with only a small unconformity, or none, between it and the Cockfield, as at Conroe for instance. This unconformity becomes pronounced farther inland. The inner tip of the Jackson is mainly terrigenous with much cross-bedding and many signs of contemporaneous erosion and deposition. The Vicksburg is often considered as closely related to the Jackson.

The Catahoula again may represent a withdrawal of the sea before heavy sedimentation. Its sands contain much volcanic ash and petrified wood. Downdip it becomes marine; and, in or just above it, there is a particular marine wedge for which the name Anahuac formation[31] has recently been designated. This is charasterized by certain microfossils (*Discorbis, Marginulina, Heterostegina, et cetera*) and is a well known geologic horizon marker. It represents a limited advance of the sea into the encroaching sediments.

The Lapara in South Texas is shown on the diagram as being the sand formed as the sea retreated after depositing the Oakville on its advance. And the Lagarto is shown as representing an advance of the sea after which came the first retreat of the Ice age. This arrangement is presented as a possibility, not as a generally accepted situation. There is nothing like unanimity of opinion about this part of the Gulf Coast geologic section.

4. LOCAL AND REGIONAL UNCONFORMITIES

Besides true unconformities, with breaks in deposition and evidence of exposure to erosion, there are irregular surfaces where land or shallow-water deposits built out quickly over marine deposits, or where other sudden changes in sedimentation took place. There are also the innumerable sharp but local breaks, common in near-shore deposits where material, once deposited, has been eroded and then, shortly afterward, has been replaced by deposition of different material. In small outcrops, and in some large ones, it may be difficult to determine to which of these types an observed break may belong.

5. LARGE-SCALE SHIFTS OF DEPOSITION

The amount of deposition varied from region to region along the coast (Fig. 6). Eocene deposition was greatest in the Rio Grande embayment. This embayment does not coincide with the present Rio Grande Valley, but is nearer the present Nueces River. It seems that, in early Tertiary time, the material

[31] Alva C. Ellisor, "Anhauac Formation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 9 (September, 1944), pp. 1355–75.

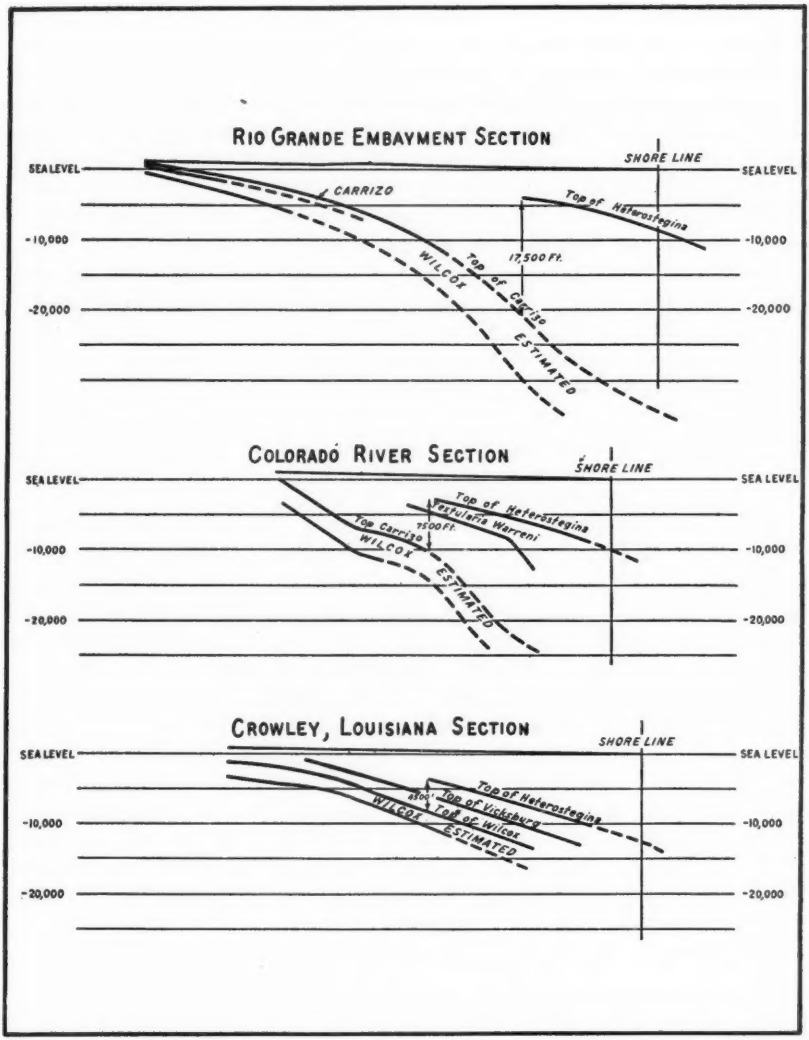


FIG. 6.—Cross sections showing variations in amount of Eocene deposition, amount in Rio Grande embayment being much greater than amount in western Louisiana.

from the Rocky Mountain front which was washed into the Great Plains basin could be carried more directly into the Gulf than it can be at present. Rivers, ancestral to the Rio Grande, Pecos, and Nueces, probably carried a greater load

of sediments than they carry to-day. Other rivers farther east, especially the Mississippi, increased in importance as time went on. By Pliocene and Pleistocene time the western branches of the Mississippi had worked back fully into the plains and into the Rocky Mountain region. Thereafter, the Mississippi supplied most of the sediments arriving at the north Gulf shore. Some of this was spread along the coast by shore currents, but the bulge of the present shore line near the mouth of the Mississippi and the known thickness of late Miocene, Pliocene, and Quaternary deposits in Louisiana show that an excess of the material remained there.

The interval from the inner tip of the Oligocene *Heterostigina* wedge (Anahuac) to the top of the Carrizo illustrates this point. This interval is 16,000 feet in the Rio Grande embayment,[32] 7,500 feet in the Colorado River region of the central Texas coast, and only 4,500 feet in western Louisiana. Figures for the downdip Wilcox, if available, might be equally impressive. Since the Oligocene, the preponderance of sediments brought to the coast by the Mississippi over that supplied by the other streams is very marked.

Oil Sands and Their Relationship to Zones of Sedimentation

Of particular interest is the distribution of sands. Oil in the Gulf Coast region has been found principally in the shore belt or marine facies of sand deposition. The updip, or so-called continental beds, generally do not produce oil nor do the sands as they "shale out" downdip. Production is ordinarily limited, in each formation, to a fairly well defined belt or trend of sand. These belts range from 10 to 30 miles in width. Some factor in the genesis of oil probably has to do with its occurrence in these particular beds, but, in addition, this shoreward, marine strip is precisely the one where sands are most plentiful, where deposition was heaviest, and where the structural adjustments attending deposition were most likely to produce faults or other changes in structure. Thus, all the features favorable to oil accumulation, including the changes which produce stratigraphic traps, are likely to be concentrated in this belt. One case in point, among many which might be mentioned, is the Saxet-Tom O'Connor trend in southwest Texas, with its great thickness of Frio sands and its development of large faults and other structural features.

Structure

Structure in the Gulf Coast region may quite properly be discussed as a feature of the sedimentation. This is so because of subsidence and the changes which occurred in the shape of the beds during their deposition.

There is no question about the subsidence, but there has been considerable argument about the reason for it. Do the sediments make a place for themselves by subsiding under their own weight or do they simply wash into a depression which is being constantly deepened for them by extraneous forces?

[32] Depth to the Carrizo is according to contours on *Tectonic Map of the United States*, Amer. Assoc. Petrol. Geol. (1944).

One question, fundamental to the whole discussion, seems to concern the strength of the earth's crust. Its strength is so great, according to one view, that the weight of sediments, even concentrated in one place, can not deform it. Another, perhaps extreme, position is that almost any addition of weight, by the accumulation of sediments, or of ice, to cite another substance, will in time produce a deformation of the supporting material.

As relating to the Gulf Coast, the discussion has been chiefly about subsidence of the Mississippi delta or of parts of it; and has passed thence to subsidence along the coast and the development of what is known as the Gulf Coast geosyncline.

Supporters of the "subsidence-under-load" position, many of them specialists in Louisiana geology, have usually adduced evidence from local conditions in support of their views. On the other hand, those taking exception to the local views have often done so by pointing out that such views are in disagreement with certain generally approved conclusions, some of which, through long acceptance and distinguished origin, have acquired almost the authority of established principles.

Probably the weight of opinion has been against the belief in "subsidence under load." It has favored, for instance, the view that geosynclines were formed by diastrophic forces only and that the earth's crust has such strength that sediments by their own weight, can effect little subsidence except by compaction. One of the basic writings on geosynclines is by Dana.[33]

Also well known are the views of W. H. Bucher as outlined in the course of his A.A.P.G. Distinguished Lecture tour in 1942.[34] Few persons question the existence of the gashes in the earth's crust which are shown on his charts. They traverse both land and sea. Those in the sea-bottom are especially impressive. Some of them are filled or partly filled with sediments and some are not. Certainly they are not produced by the accumulation of sediments. In spite of this the opinion is more and more freely expressed that subsidence under load has been a feature of the accumulation of sediments in some typical geosynclines such as the Appalachian geosyncline. Many of those who have made a special study of Gulf Coast sedimentation favor that opinion.[35]

R. J. Russell, in writing of the Mississippi delta, says that general subsidence is proved by changes in the elevations of bench-marks and that sinking takes

[33] James Dwight Dana, "On Some Results of the Earth's Contraction from Cooling. Including a Discussion of the Origin of Mountains, and the Nature of the Earth's Interior," *Amer. Jour. Sci.*, 3d Ser., Vol. 5 (1873), pp. 423–43; 474–75. Geosyncline defined.

[34] See also: W. H. Bucher, *The Deformation of the Earth's Crust*. Princeton Univ. Press (1933). Reviewed by Ralph Stewart, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), pp. 1093–97.

[35] Richard Joel Russell, "Gulf Coast Geosyncline: America's Great Petroleum Reserve, Geomorphogeny," *XVII Internatl. Geol. Cong. Moscow, 1940*, pp. 255–57.
Henry V. Howe, "Gulf Coast Geosyncline; America's Great Petroleum Reserve, Stratigraphy," *ibid.*, pp. 255–63.

place most rapidly in regions of heavy sedimentation.[36] This could be by compaction. Submergence of cultural features such as bridges, houses, and villages of white men and of Indians has carried the evidence of subsidence back a few hundred or perhaps a thousand years. The Recent and late Pleistocene pockets of sediments mentioned in a previous paragraph, are compared by Russell with ladles, the bowls of which are in the delta and the handles up stream. Their existence and configuration has been proved by the record of the sands found in many deep water wells. These bowls are as much as 3,000 feet deep.[37] Lawson has also written about subsidence of the Mississippi delta.[38]

1. DETAILED FEATURES OF LOCAL STRUCTURE

The structure and stratigraphy of the whole coastal belt, to a depth of 13,000 feet, more or less, are better known probably than those of any other region of similar size. This information is a by-product from the drilling of thousands of wells for oil. Electrical logs of these wells have made it possible to work out the structure in detail. All the evidence indicates development of structure along with sedimentation and subsidence.

Aside from regional warping, faults, and salt domes are the structural features most characteristic of the area. It is in association with them that much of the oil is found and the detailed knowledge of their structure is worked out by wells which were drilled close together to develop the oil pools. There appears to be the same relation of structure to sedimentation for the regional features that there is in the local areas around the salt domes. The domes are an expression in miniature of the forces operating in the region and a sketch of the structure around them will illustrate the structural situation as a whole.

Salt domes in this region are found in all stages of their growth above the deep bed of salt in which their cores are believed to have originated. Appare tly all of them did not start to grow at the same time. In the earliest stage we know of, the strata are only slightly arched at a depth of 12,000 ot 15,000 feet—the extreme reach of the drill. In the latest stage, salt has pierced nearly to the surface with beds dipping away in all directions. Around domes of an intermediate stage, the deeper strata lie at a steep incline against the salt. Higher, the beds dip away less steeply. Near the surface the beds are arched over the salt and the arch becomes flatter nearer and nearer the surface. The beds are thinner over the top of the dome than they are around it. Such a condition suggests that the series of beds was not complete when the salt began to rise, but that the growth of the domes was contemporaneous with the deposition, over a long period of time.

[36] R. J. Russell and R. D. Russell, "Mississippi River Delta Sedimentation," *Recent Marine Sediments*, Amer. Assoc. Petrol. Geol. (1939).

[37] John W. Frink, "Subsurface Pleistocene of Louisiana," in "The Sand and Gravel Deposits of Louisiana," *Louisiana Geol. Survey Bull. 19* (1941).

[38] A. C. Lawson, "Mississippi Delta—A Study of Isostasy," *Bull. Geol. Soc. America*, Vol. 53, No. 8 (1942).

The salt is said to have risen through the sediments, but this rise is relative only, beds having come down more than the salt has come up from the original position. The whole situation involves subsidence on a grand scale. The salt was deposited, at most, only a few hundred feet below sea-level and now it is covered by and intrudes an estimated 20,000 to 30,000 feet of sediments, all of which, so far as we know, were deposited at or near sea-level.[39]

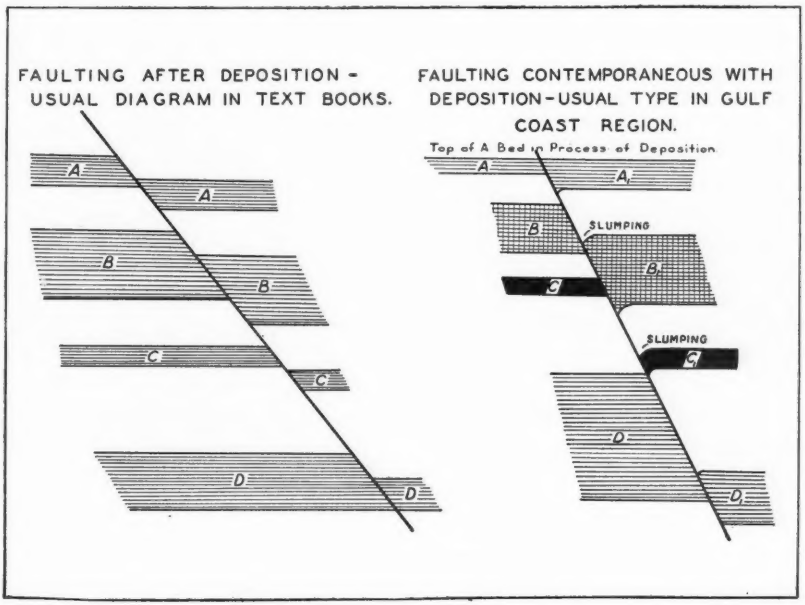


FIG. 7.—Diagrams contrasting structure produced by faulting subsequent to deposition of beds with that produced by faulting which went on continuously while beds were being deposited. In one case, amount of throw is same for all beds. In other, throw is much greater for older beds than it is for later beds.

Generally, the domes which show any marked evidence of uplift at an intermediate depth, 8,000 feet more or less, show it in gradually diminishing amounts toward the surface. Perhaps the continuous growth is shown by the faulting over these domes better than it is by any other feature (Fig. 7).

[39] E. DeGolyer *et al.*, *Geology of Salt Dome Oil Fields*, Amer. Assoc. Petrol. Geol. (1926), p. 782. Salt dome articles in *Gulf Coast Oil Fields*, Amer. Assoc. Petrol. Geol. (1936).

W. E. Wallace, Jr., "Structure of South Louisiana Deep-Seated Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 9 (September, 1944), pp. 1249–1312.

Willis G. Meyer, "Grabens in Gulf Coast Anticlines and Their Relation to Other Fault Troughs," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 4 (April, 1944), pp. 541–53.

Progressive faulting is indicated by the greater throw of A′, B′, and C′ as compared with A, B, and C, and the greater thickness of B′ and C′ as compared with B and C. Bed A is forming at the surface and sinking as it does so. In addition, movement along the fault is carrying the bottom of A′ down with reference to A while waves or currents or other agencies maintain the top of the bed at the same level on both sides of the fault. Thus, A′ increases in thickness continually as compared with A until it is superceded by another bed. Moreover, the whole thickness of the section on the downthrown side of the fault is greater than it is on the upthrown side, and the throw, of only a few feet in the Pleistocene, has increased with the passage of time to several hundred feet in the deeper beds. Electrical logs have shown that this feature is probably characteristic of all salt domes in the Gulf Coast region.

A common development in faulting on salt domes during the arching stage is for a graben to appear on top as though stretching of the beds had caused a wedge of formations to slump down as the keystone of an arch might slip if the arch were pulling apart.[40] Electric-log cross sections of the domes commonly reveal this feature. Parallel and intersecting faults produce a complicated pattern. Dip faults develop through shearing on the flanks of the dome; and, as the salt stock begins to pierce the arched beds, a horst situation develops over the dome.

2. REGIONAL STRUCTURE AND DEVELOPMENT OF GEOSYNCLINE

The pattern of regional faulting throughout the Gulf Coast area, with its grabens and other features, is strikingly similar to that around the salt domes and might be explained in the same way—by stretching and arching of the beds. This is accomplished in the regional features by subsidence of the accumulating deposits, along with a rise inland which tilts and bends the whole series. A tendency of beds on the downthrown side to slump and to dip toward the fault is shown near these regional faults as it is also on the salt domes. This slumping of the downthrown beds near the fault appears to be a feature of the faulting in this region. Instead of being dragged upward along the fault, as might be expected and as is usually shown on text-book diagrams, the downthrown beds near the fault are commonly bent downward along it. This slumping or down-bending is measured in tens or hundreds of feet. In this region oil sometimes accumulates in anticlines formed in this way near faults, on the downdip side. There is also, for the regional faults, a difference in the thicknesses of beds on the two sides. The downthrown side is thicker, and the same progressive increase of the throw with depth is noted. These features can be observed on an electrical-log cross section of any large fault field (oil or gas) in the Gulf Coast region.

Inland, along the Mexia fault zone, for example, the faults have a throw of several hundred feet in the surface beds. Not everywhere does the displacement along these faults increase with depth though in many places it does.[41] Continual

[40] W. E. Wallace, Jr., *op. cit.*

[41] F. H. Lahee, "Oil and Gas Fields of the Mexia and Tehuacana Fault Zones," *Structure of Typical American Oil Fields*, Vol. 1, Amer. Assoc. Petrol. Geol. (1929).

changes in structure accompanying deposition are not so noticeable in this inner belt as they are nearer the coast.

Nearer and nearer the coast, the faults in the surface beds have less and less throw and are more difficult to find. In the near-shore region, faults with hundreds of feet of throw at depth can be mapped all the way to the surface, but the throw gradually diminishes upward until on the actual surface it may be marked by a typographic change of only a few feet. This is not everywhere a scarp since

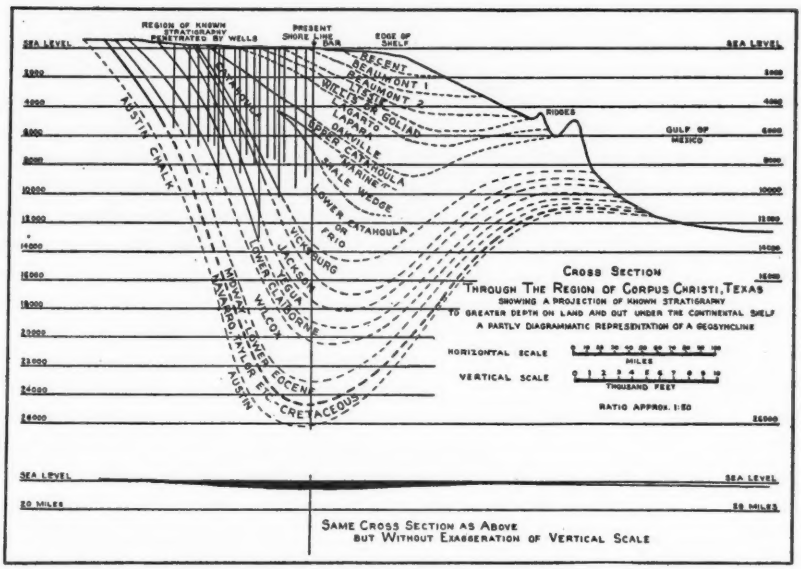


FIG. 8.—Diagram representing possible nature of Gulf Coast geosyncline. Upper left part of section drawn according to actual knowledge obtained in drilling of wells. Profile of sea bottom is also correct, according to soundings. Remainder of section represents attempt to complete picture in a way which seems reasonable. Depth of Cretaceous-Eocene contact in bottom of syncline is thought to be in harmony with geophysical data. Section is taken northwest and southeast through Corpus Christi, Texas.

the change in elevation may be spread by erosion over 50 or 100 feet.[42] However, it is commonly well marked enough to show recent movement.

These gradual changes, great at depth and diminishing toward surface, indicate structural adjustment during deposition and subsidence. Some considerations which suggest that the subsidence was due to loading are as follows.

In the part of the cross section (Fig. 8) where definite information about structure has been obtained from drilling, the shape of the beds suggests that the trough of subsidence moved seaward along with the accumulation. The profiles

[42] W. Armstrong Price, "Role of Diastrophism in Topography of Corpus Christi Area, South Texas," *Gulf Coast Oil Fields*, Amer. Assoc. Petrol. Geol. (1936), p. 205.

are similar but appear to be shifted progressively seaward. This is readily explained by subsidence along with an accumulating load. Other explanations seem (to the writer) more involved.

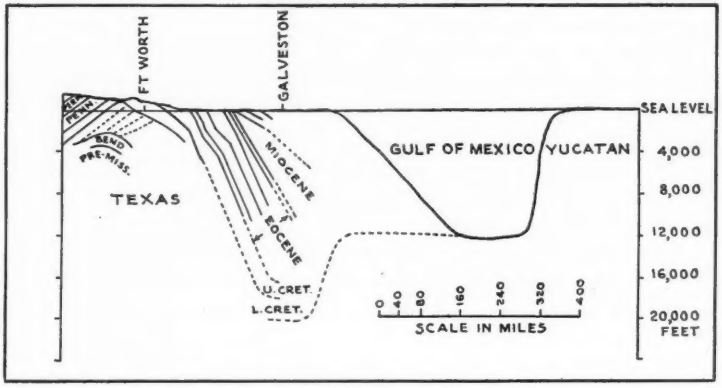
Gravity investigations, according to Barton, Ritz, and Hickey, indicate that the axis of the present geosynclinal trough is slightly inland from the present shore line.[43] Figure 9 shows the depth of the syncline to be approximately 25,000 feet down to the Cretaceous beds. The attitude of the beds penetrated by the deeper wells (already deeper than the floor of the Gulf) indicates that the Cretaceous-Eocene contact might easily be at a depth of 25,000 feet in the syncline. Geophysical data also suggest such a depth. That is twice the depth of the floor of the Gulf of Mexico beyond the continental shelf. The geosynclinal trough is thus a well marked feature indicating considerable subsidence. If it has maintained and is maintaining its present position (in-shore), it is being or has been over-ridden by the sediments and they have crossed this barrier and are building independently of it out into the Gulf. If this is so and if the subsidence is continuing at this fixed position, there should be some sign of sinking inland from the shore and of a shift of drainage so as to deposit sediments over the axis of the syncline. There is no indication of such a shift now, or of any similar shift, on a large scale at least, in the past.

It seems easier (for the writer) to believe that the shape of the trough is a composite of past and present; that it is moving seaward along with the sediments; that subsidence is now principally on the seaward flank of the trough over which the sediments are now accumulating; and, that as they continue to accumulate, the bottom of that flank will be pushed down while the landward flank rises slightly. In this way an adjustment will be maintained and the geosyncline will shift sidewise into the Gulf.

Development of geosyncline.—A history of the geosyncline is postulated as follows. Possibly the subsidence which led to its development started before Tertiary time. There seems to be evidence of subsidence during deposition in some of the Gulf Coast Cretaceous beds. Certainly the later Cretaceous beds belong structurally to the sequence which is involved in the subsidence. But sometime in the early Tertiary the heavy concentration of sediments southeast of the Balcones zone, may have accentuated the faulting there and initiated a depression parallel with the shore, a depression which has moved progressively toward the Gulf along with the sedimentation.

Perhaps there has been a diastrophic subsidence in the northwest part of the Gulf of Mexico, but it seems reasonable to accept some adjustment of structure to the weight of sediments even if a master role is not assigned to it. Those who believe that subsidence took place quite independently of loading, probably do

[43] D. C. Barton, C. H. Ritz and Maude Hickey, "Gulf Coast Geosyncline," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 12 (December, 1933), pp. 1446–58.
Richard Joel Russell, "Lower Mississippi Delta," *Louisiana Geol. Survey Bull. 8* (1936), p. 180.



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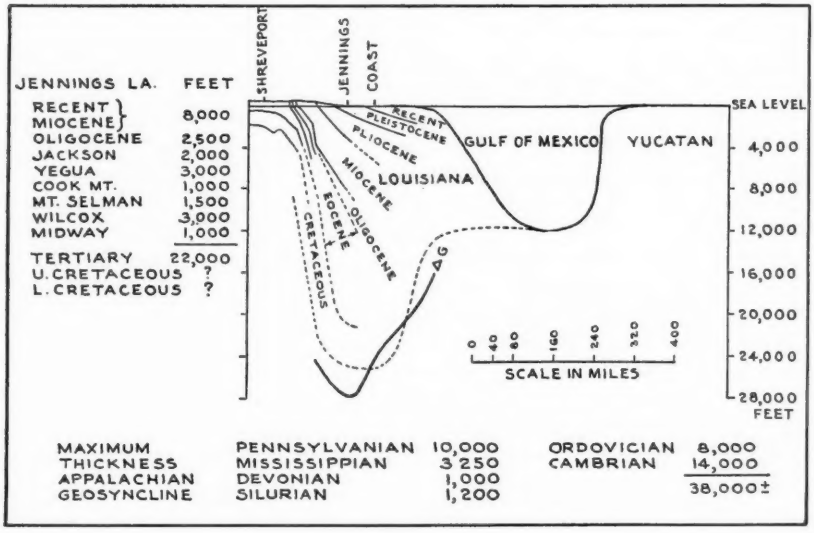

B

FIG. 9.—Diagrams of Gulf Coast geosyncline, from article by D. C. Barton, C. H. Ritz, and M. Hickey, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 12 (December, 1933), p. 1448. Based largely on geophysics. A. Section from Fort Worth, Texas, through Galveston, to Sigsbee Deep. B. Section from Sabine uplift, through Jennings, to Sigsbee Deep.

not go so far as to say that source conditions and changes in drainage systems bringing sediments to the coast, first in one place then in another, were all adjusted to the position and size of the depression. To them, possibly, depth of water over the depression or position of shore line around it, may make up for lack of perfect adjustment between size of the depression and amount of sediments available. Yet there never seem to have been any deep unfilled holes in this geosyncline. It is easier to conclude that where the sediments accumulated in large amount, their weight brought about some adjustment of structure to help make room for them. This, according to Russell, is the case on all large deltas the world over. If the strength of the earth's crust seems too great to permit adjustment under load, it may be well to consider that the cores of Gulf Coast salt domes are believed to pierce through thousands of feet of formation with only the difference of specific gravity between salt and shale to drive them. These gravities are: salt (NaCl) about 2.19, shales up to 2.3 or 2.4. The material pierced may be more easily deformed than deeper parts of the crust, but perhaps some adjustment to load may also take place in this upper material without affecting the deeper part of the crust.

It is suggested that a thorough study in this region might yield the data to decide some of the questions about subsidence.

Figure 9 represents D.C. Barton's idea of this geosyncline[44] about which he wrote and talked so extensively that Schuchert, in his text book on *Historical Geology*, calls it the "Barton geosyncline."

Figure 10 shows the Appalachian geosyncline for comparison.

The upper left hand part of Figure 8 shows the known part of the Gulf Coast sediments, that is, the part which has been penetrated by wells. The bottom of the known mass is 1,000 feet below the floor of the Gulf. Below that the position of the beds is a surmise. There is no information to suggest that they do not extend to deeper levels. They may be expected to flatten gulfward. As they extend seaward, each of them should pass beyond the zone of its maximum thickness and gradually thin out as the seaward limit of clastic sedimentation is approached. Beyond the depressed zone, the beds are shown rising to the present Gulf floor as they thin out. This is merely the writer's inference.

The irregularities on the profile of the shelf between 150 and 200 miles off shore are based on soundings. The relief there is perhaps 2,000 or 3,000 feet. There are many such elevations and depressions on the front of the shelf. These may be remnants of the canyons, previously mentioned, or they may be old features of the Gulf floor which are being covered by the advance of the mass of Cenozoic sediments.

The lower diagram in Figure 8 shows the cross section in its true proportions. It reminds us that the mass which we have been considering is, after all, very thin in comparison with its extent, that the beds have been deposited on a very slight dip, and, that even after considerable steepening by subsidence, the dip is still rather slight.

[44] D. C. Barton, C. H. Ritz and Maude Hickey, *op. cit.*

Summary and Conclusions

Most of the features and problems of Gulf Coast geology pass in review when its sediments are studied in a broad way. This may result from the nature of the study itself. If such matters as derivation of material, routes of transportation, and consequences of the sedimentation are included in the study, it will assume at once a central position in the geological study of any region. But this is true,

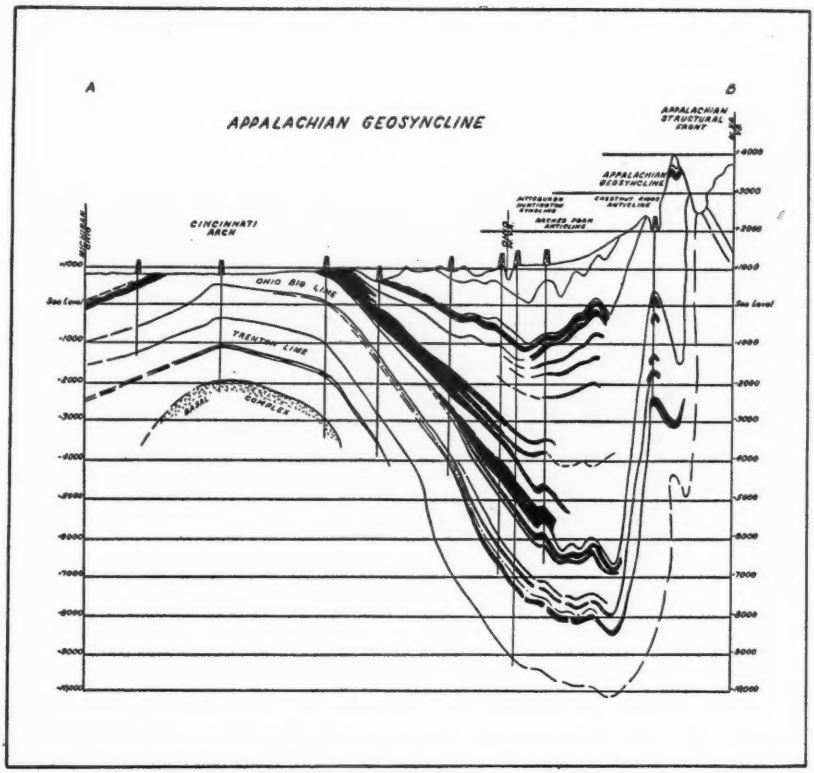

Fig. 10.—Diagram of Appalachian geosyncline for comparison. Probably more study has been given to this than to any other geosyncline. This syncline developed between a landmass on the east and a mass on the west; it was sometimes land and was sometimes submerged beneath a shallow sea, whereas the Gulf Coast geosyncline has a near-landmass on only one side of it.

perhaps especially, for geology of the Gulf Coast, because of the dynamic aspect of its sedimentation. Even the geologic structure of the province as a whole and of its smallest details has developed during the deposition of its sediments and as a result of forces then operating. Apparently the movement along faults, the growth of salt domes, and the gradual tilting of the whole series of beds are still proceeding along with subsidence and the deposition of sediments.

This region of active deposition offers special advantages for a study of the growth of a series of deposits and of their changes in position and structure during compaction and subsidence. The Gulf Coast region is otherwise adapted to the study of sedimentation by virtue of the coincidence of many favorable factors. One of the greatest rivers of the world is depositing its tremendous load of sediments along this coast, and the delta being formed is, in many ways, typical of large deltas the world over. Many lesser rivers also bring material to the coast where shore currents and waves transport and distribute it. A geosyncline is in the process of being formed, and back from the coast are the systems of transportation and the areas of source material of various types for study.

The data and facilities available for study are plentiful and impressive. The region is easily accessible and the whole environment, from source areas to places of deposition, is well developed economically. The climate, surface geology, physiography, and hydrology have been studied extensively, and many publications are available.

In addition, there is a special mass of information available which is undoubtedly more complete for this region than for any other of equal size. Reference is made to the records of the thousands of wells which have been drilled for oil. These records include the samples (in some cases to a depth of 15,000 feet), the logs made from an examination of these samples, and, particularly, the electrical logs which are available for practically all the wells drilled during the past 10 years. It so happens that the numerous alternations between sand and shale in the Gulf Coast series of beds can be recognized better, in the subsurface, by means of the difference in their electrical properties, as revealed in these logs, than they can be in any other way. The electrical logs show the changes of formation so clearly that by means of them the subsurface structure can be mapped in detail. It is only since such logs became available that many of the structural characteristics described in this paper have been recognized.

In preparing this paper, the purpose was not so much to present full information about any subject. It was more to show what subjects for research and study the Gulf Coast has to offer.

Among these subjects is one which might appear to be the central theme of this paper. That is the inter-relation of sedimentation and subsidence. With this is associated the explanation of the kinds of geologic structure found in the Gulf Coast region. It is not inferred that such structure is confined to the Gulf Coast Probably structure showing many similarities to it may be found in any of the regions, large deltas for instance, or large offshore deposits, where heavy sedimentation has been in progress for a long time. A feature which will be missing in most cases is the deep bed of salt and the stocks arising from it. But, in each place, along with the special types of structure which the local and regional situation has produced, one may find indications that sedimentation, subsidence, and the development of structure have been simultaneous processes. Probably lacking also, will be the oil wells with their electric logs to reveal the types of

structure. But it is hardly possible that any of the Gulf Coast structure types is unique and probably evidence of their presence elsewhere will accumulate as time progresses.

However, there is no such assemblage, outside the Gulf Coast region, of information easily available for this study of the interplay of subsidence and sedimentation and the consequent development of structure. With its possibilities for enlightenment about such subjects as "Subsidence under load and the development of a geosyncline," this mass of evidence is a unique offering from the Gulf Coast region to the science of geology.

The deposition of sand along a shore and its distribution by ocean currents in belts parallel with the shore, is another of the larger studies for which the Gulf Coast region offers facilities. It will no doubt be resumed after the war.

Groups and trends of oil-bearing sands is another Gulf Coast subject which deserves further study.

Altogether, the Gulf Coast may offer more to the student of geology in general, and of petroleum geology in particular, than has been heretofore supposed.

The region, however, has received some very notable attention. The writings of the Louisiana State geologists about the Mississippi River and delta are becoming classic, and many other writers about the Gulf Coast have made contributions, of a high order, to geological literature. References to them in this article are inadequate but those given refer to many others, and anyone interested in the subject may readily find what he needs. There is, in fact, a wealth of material upon which the student of this region may begin.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 9 (SEPTEMBER, 1945), PP. 1336-1348, 6 FIGS.

PRE-PERMIAN AXES OF MAXIMUM DEPOSITION IN WEST TEXAS[1]

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ABSTRACT

All of the Paleozoic rocks of the Marathon Mountains have been referred to as having been deposited in the Llanoria geosyncline. The Pennsylvanian rocks of the Marathon Mountains are the thickest of any Pennsylvanian rocks known in West Texas but the pre-Pennsylvanian rocks, with the possible exception of the Cambrian sandstone, attain their maximum thicknesses north and west of the Llanoria geosyncline.

The Llanoria geosyncline, if it is considered as a deep trough developed adajcent to the old landmass of Llanoria, was not developed until the end of Mississippian time. Only Pennsylvanian rocks can be considered as having been deposited in the Llanoria geosyncline.

Diagrammatic cross sections show the different positions of the axis of maximum deposition in West Texas from Ordovician time through the Pennsylvanian period.

INTRODUCTION

The pre-Pennsylvanian as well as the Pennsylvanian rocks of the Marathon and Ouachita mountains have long been regarded as having been deposited in the Llanoria geosyncline. This geosyncline has been pictured as a deep trough developed immediately in front of and parallel with the old Llanoria landmass. The sediments that were deposited in this geosyncline have been considered as being derived from the aforementioned landmass[3] (Fig. 1).

This interpretation of depositional conditions during Pennsylvanian time is adequate since the Pennsylvanian rocks of the two areas are much thicker than they are any place else in the Mid-Continent region.

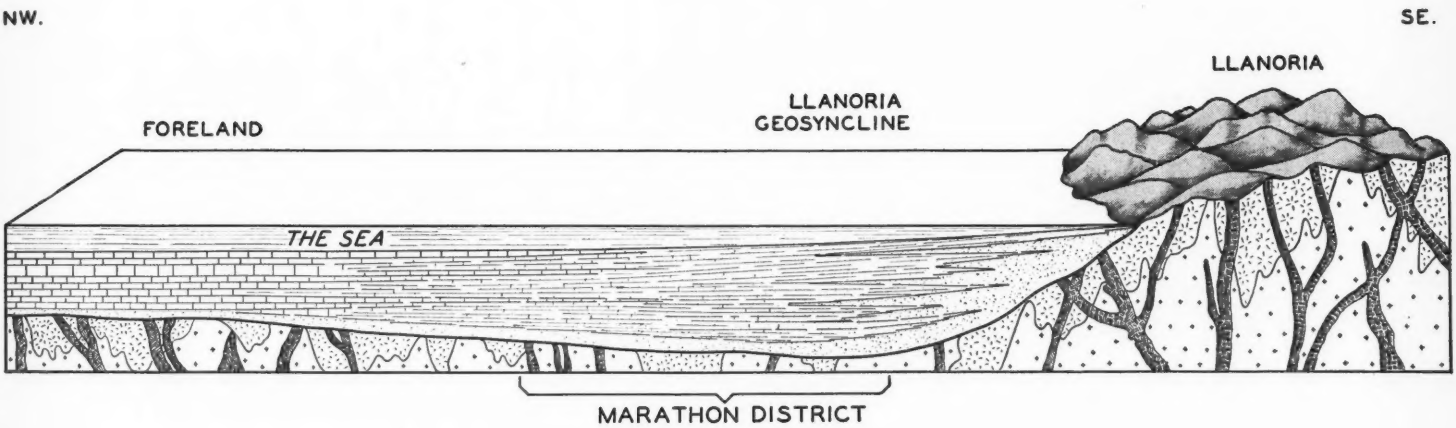
Subsurface sections in West Texas and surface sections in Oklahoma, however, show that the thickest sections of pre-Pennsylvanian rocks are not in that area assigned to the Llanoria geosyncline but considerably farther north and west.

These thicker sections are made up of fine shales, limestones, and a few sandstones, all of which contain a calcareous fauna. The equivalents of these thick sections as found in the Marathon Mountains are much thinner and are made up of clastics and cherts. There are many black shales, sandstones, and flaggy limestones.

[1] Manuscript received, May 10, 1945.

[2] Magnolia Petroleum Company. The writer wishes to express his appreciation to S. A. Thompson and the Magnolia Petroleum Company for permission to publish this paper. Much of the information has been obtained from well logs in the files of the company's Midland office. These logs have been largely prepared and interpreted by H. A. Hemphill and the writer. Many helpful discussions were had with Mr. Hemphill during the preparation of the manuscript. The writer extends his appreciation to Leslie S. Page for drafting the diagrams.

[3] E. H. Sellards, "Pre-Paleozoic and Paleozoic System," "Geology of Texas, Vol. 1, Stratigraphy," *Univ. Texas Bur. Econ. Geol. Bull. 3232* (1932), pp. 21–23.
Philip B. King, "Geology of the Marathon Region, Texas," *U. S. Geol. Survey Prof. Paper 187* (1937), p. 19, Fig. 16, Pl. 20.
West Texas Geological Society, "Resume of South Permian Basin," *Bull. Geol. Soc. America* Vol. 53 (1942), p. 543.



PHILIP B. KING

INTERPRETATION OF THE

PROBABLE GEOGRAPHY OF THE MARATHON REGION IN ORDOVICIAN TIME.

FROM U.S.G.S. PROFESSIONAL PAPER N°187, p. 44

FIG. 1

The writer questions the advisability of referring to the pre-Pennsylvanian rocks of the Marathon and Ouachita mountains as geosynclinal deposits if the Pennsylvanian rocks are referred to as geosynclinal deposits. They appear to be more adequately explained as near-shore deposits laid down on a gently sloping profile. These deposits grade into calcareous shales and limestones farther from shore. The calcareous shales and limestones are much thicker than their near-shore equivalents, indicating that in pre-Pennsylvanian time the greatest amount of subsidence was not adjacent to Llanoria but farther north.

An objection to referring to the pre-Pennsylvanian rocks in the Marathon Mountains as geosynclinal deposits was recorded by E. H. Sellards in 1935. This objection was based on the fact that these deposits are not excessively thick.[4]

In the present paper, pre-Pennsylvanian deposits of the Marathon Mountains are compared with their seaward equivalents on the north and northeast in an effort to show that the Marathon-Ouachita facies are not geoysnclinal in the same sense as the Pennsylvanian rocks of this area. If we consider the thick accumulations of Pennsylvanian rocks that are exposed in the Marathon Mountains as being geosynclinal, the relatively thin accumulations of pre-Pennsylvanian rocks can not be considered as geosynclinal; or at least if these deposits are related to a geosyncline, it is more shallow in type and its axis of maximum deposition does not coincide with the Pennsylvanian axis of maximum deposition but lies farther north.

The same comparisons of the rocks found in the Ouachita Mountains with those of the Arbuckle Mountains can be made and the same results achieved. W. H. Bucher has referred to the early Paleozoic geosyncline of Oklahoma as the Wichita-Arbuckle geosyncline to differentiate it from the Pennsylvanian Ouachita geosyncline.[5]

This explanation of the relationship of the pre-Pennsylvanian rocks of the Marathon and Ouachita mountains to the basinward equivalents requires a restriction of the use of the term Llanoria geosyncline. Only the Pennsylvanian rocks can be correctly assumed as being deposited in the Llanoria geosyncline since it was not formed until the end of Mississippian time.

This dating of the Llanoria geosyncline requires that the Tesnus formation be entirely Pennsylvanian in age. If we accept the alternate correlation assigning the lower part of the Tesnus to the Mississippian, then we must assume that the Llanoria geosyncline was formed during late Mississippian time instead of at the end of Mississippian time.

E. H. Sellards has offered one possible explanation of the fact that the pre-Pennsylvanian sediments of the Marathon region are thinner than their northward equivalents. He has suggested that the maximum thickness of pre-Carbonif-

[4] E. H. Sellards, "Major Structural Features of Texas East of Pecos River," *Univ. Texas Bur. Econ. Geol. Bull. 3401* (December, 1935), pp. 36–38.

[5] Walter H. Bucher, *The Deformation of the Earth's Crust*, pp. 364–74. Princeton University Press (1933).

erous sediments may be on the south and east of the exposures in the Marathon and Ouachita regions.[6]

The writer does not believe that present evidence points to this explanation, but if future drilling should prove this to be the case, then the interpretation offered here would have to be discarded.

This paper is likely to be criticized in that it deals with a large and complex problem in a very few pages. Some will no doubt feel that by discussing whole systems of rocks rather than smaller units, an incomplete picture is obtained. These criticisms have weight but if all the details were given, the paper would become so cumbersome that the whole point would be missed. At the risk of being too brief, the discussion has been limited in an effort to emphasize the one point that the pre-Pennsylvanian rocks of the Marathon Mountains can not be referred to as geosynclinal in the same sense as the Pennsylvanian rocks.

The diagrams follow the pattern of the text in that they may be overly simplified. For example, after Cambrian time any of the post-pre-Cambrian rocks could have been involved in folding along their edges bordering the Llanoria landmass. To substantiate this we find boulders of Cambrian and early Ordovician rocks in the Woods Hollow formation of middle Ordovician age. However, evidence of pre-Woods Hollow folding is not found in the outcrops of the region.[7] The writer does not attempt to reconstruct in this paper these complicated details of geological history.

Comparison of Pre-Pennsylvanian Rocks of Marathon Mountains and Their Thicker Equivalents on the North

CAMBRIAN

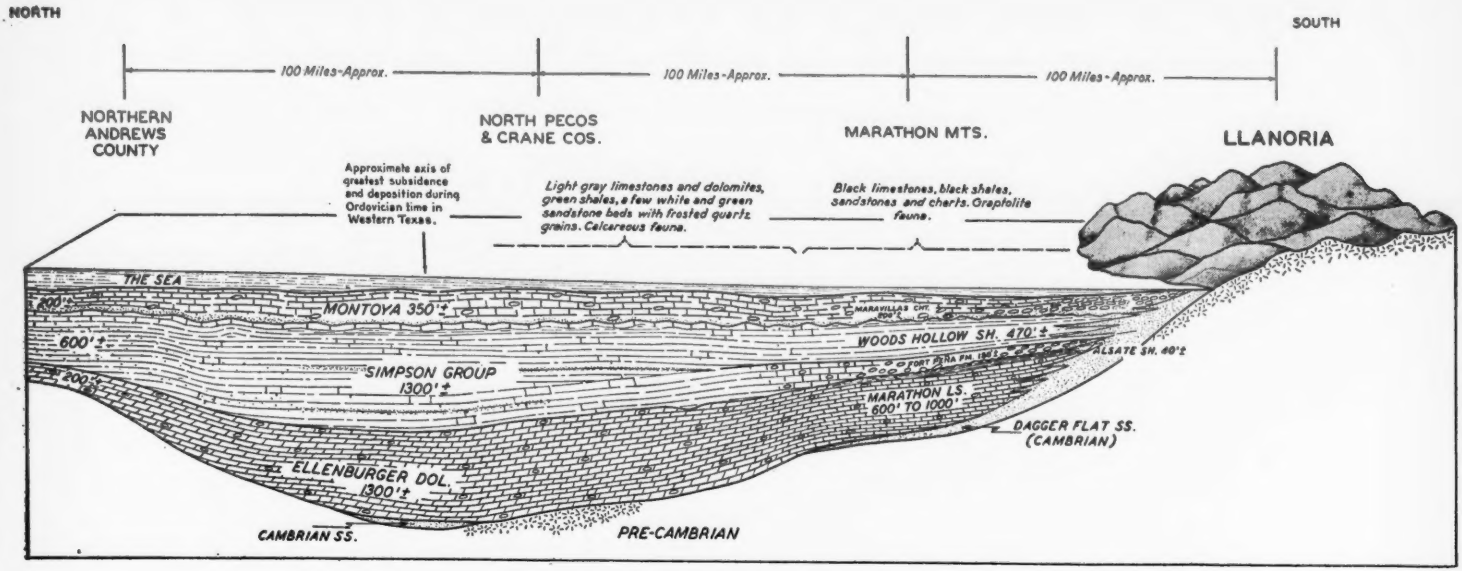
The Cambrian of the Marathon Mountains is represented by the Dagger Flat sandstone, which is a fine- to coarse-grained sandstone with shale partings. Its maximum thickness is not known with certainty but it is at least 200 feet thick in places. Its base has not been established.

North from the Marathon Mountains in the area of northern Pecos County, the Cambrian sandstone has been found in subsurface work. It is commonly arkosic and varying in thickness. In every place that it has been found it is of less thickness than in the Marathon Mountains. This suggests that during Cambrian time the axis of maximum deposition in West Texas struck through the area of the Marathon Mountains.

In the Llano uplift and in the Arbuckle Mountains, the Cambrian is much thicker than in the Marathon and Ouachita mountains. This is strong evidence that maximum deposition in Cambrian time was in the area assigned to the foreland rather than that assigned to the Ouachita-Marathon geosyncline.

[6] E. H. Sellards, "Major Structural Features of Texas East of Pecos River," *Univ. Texas Bur. Econ. Geol. Bull. 3401* (1935), p. 37.

[7] Philip B. King, *op. cit.*, pp. 46–47.



DIAGRAMMATIC CROSS SECTION

PRE-PENNSYLVANIAN ROCKS AT CLOSE OF ORDOVICIAN PERIOD

FIG. 2

The writer feels that further knowledge of the subsurface position of the Cambrian is necessary in order to know with certainty where the maximum axis of deposition was.

ORDOVICIAN

The Ordovician rocks are well represented in both the Marathon Mountains and in the subsurface on the north and northeast. In the Marathon Mountains the Ordovician rocks are between 1,300 and 2,000 feet thick and consist of black shales, black flaggy limestone, sandstone, and large developments of chert. The black shales contain a graptolite fauna.

In the subsurface on the north and northeast in northern Pecos and Crane counties, the Ordovician consists of 3,000± feet of light-colored dolomites, light-colored limestones, green very fine-textured shales, and a few beds of sandstone containing well rounded frosted quartz grains. These rocks have a calcareous fauna.

Farther north in Andrews County, subsurface work has shown a thinning of the Ordovician rocks to 1,000± feet and the appearance of black shales in the Simpson group. This has recently been displayed in the Shell Oil Company's Cox No. 1,in the northwestern corner of Andrews County.

To the writer the most logical explanation of the relationship of the foregoing facies is to picture a northward-dipping normal shore profile away from Llanoria on which the Ordovician rocks were deposited. The thinner clastics, black shale, black limestone, and chert deposits were laid down near shore, while away from the shore the finely textured shales, light-colored dolomites, and limestones were deposited (Fig. 2). The non-clastic green shales and light-colored limestones and dolomites which are farther from the shore line are thicker than the near-shore clastic and chert deposits. Farther north, these thick clacareous deposits become thin and again assume near-shore characteristics.

We can assume that the greatest amount of subsidence during Ordovician time took place along an axis that extends through northern Pecos and Crane Counties instead of immediately in front of Llanoria (Fig. 3).

SILURIAN

Silurian rocks are not present in the Marathon Mountains[8] but on the north they are found ranging from 300 to 500 feet in thickness, consisting of light gray limestones and dolomites. In Pecos and southern Crane counties, green shale is developed at the top of the Silurian.

In Andrews County, Texas 1,500± feet of Silurian-Devonian rocks have been found. The writer shows the upper 1,100± feet of this thickness as Devonian in age and the lower 400± feet as Silurian. This division is largely based on lithology since as yet very little paleontological evidence is available and its accuracy has not been definitely established, but this explanation does appear to be the simplest.

[8] E. H. Sellards, "Geology of Texas," Vol. 1, *Univ. Texas Bur. Econ. Geol. Bull. 3232* (1932), p. 86.

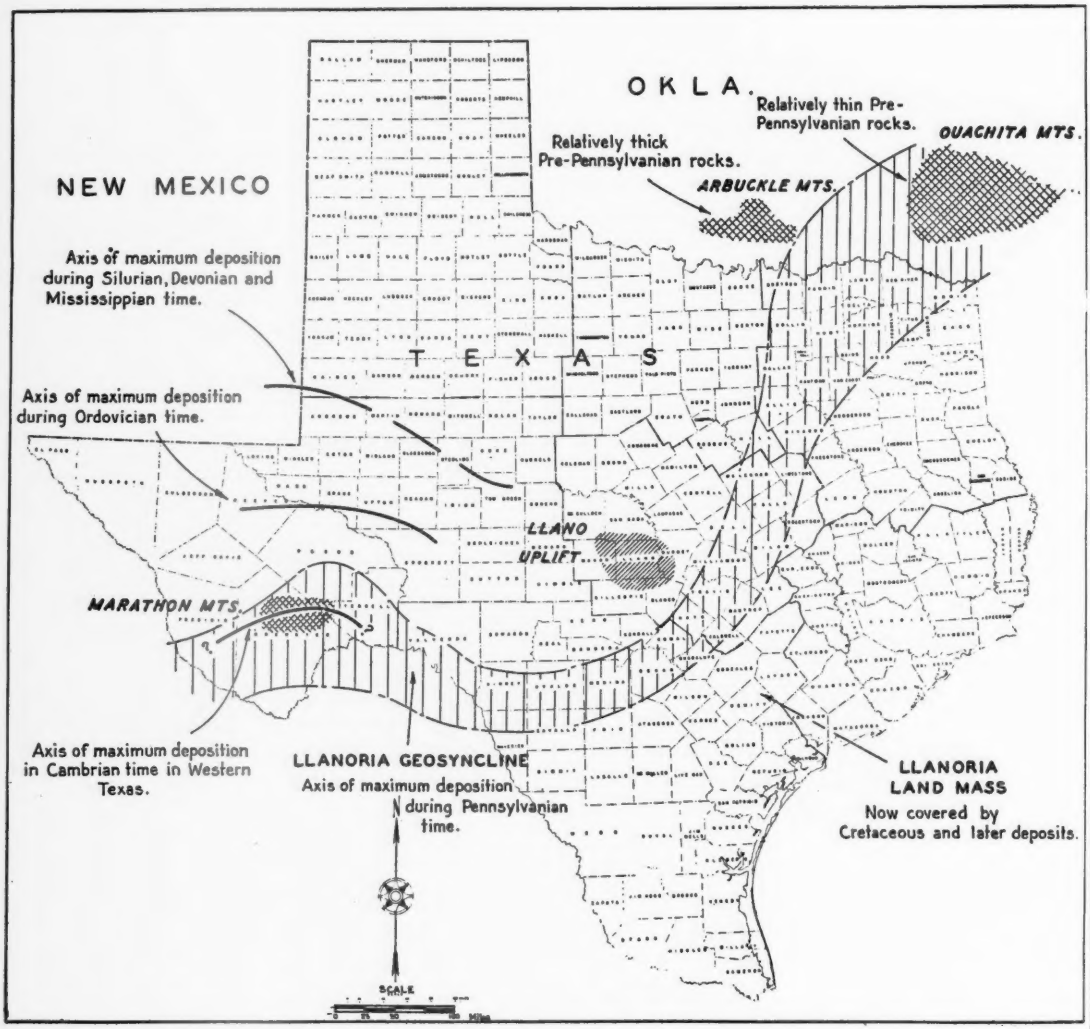

OKLA.
Relatively thin Pre-Pennsylvanian rocks.
OUACHITA MTS.
Relatively thick Pre-Pennsylvanian rocks.
ARBUCKLE MTS.
NEW MEXICO
Axis of maximum deposition during Silurian, Devonian and Mississippian time.
T E X A S
Axis of maximum deposition during Ordovician time.
LLANO UPLIFT
MARATHON MTS.
Axis of maximum deposition in Cambrian time in Western Texas.
LLANORIA GEOSYNCLINE
Axis of maximum deposition during Pennsylvanian time.
LLANORIA LAND MASS
Now covered by Cretaceous and later deposits.
SCALE
Miles

FIG. 3.—Map of Texas showing location of features discussed.

The possibility exists that this great thickness of rocks is mostly, if not entirely, Silurian in age. If the latter correlation is found to be correct, then more complicated depositional conditions were present during Silurian and Devonian time than are pictured in the diagrams in this paper.

In Silurian time there was little, if any, deposition in the area referred to as the Llanoria geosyncline in West Texas. Instead, deposition took place on the north in that area commonly referred to as the foreland.

This is evidence that during Silurian time in West Texas the greatest amount of subsidence was not in the area commonly referred to as the Llanoria geosyncline, but on the north in what has long been referred to as the foreland (Fig. 4).

In the Ouachita Mountains the Silurian is 1,500 to 1,800 feet thick while in the Arbuckle Mountains it is only 300± feet thick. This indicates that during the Silurian there was more subsidence in the area assigned to the Llanoria geosyncline than in the foreland of the region.

DEVONIAN

The Devonian system is represented in the Marathon Mountains by the Caballos novaculite. This is a series of beds of chert and novaculite with a very siliceous sand stringer here and there. It ranges in thickness from 200 to 600 feet.

On the north in subsurface the Devonian is represented by 1,100± feet of cherty limestone and dolomite. The chert is the subordinate constituent of this facies. In some sections it is almost entirely absent.

This greater thickness of Devonian rocks, in what has been called the foreland facies, shows that the greatest amount of subsidence during Devonian time was not in the region of the Llanoria geosyncline but rather on the north under the so-called foreland facies (Fig. 4 and Fig. 3).

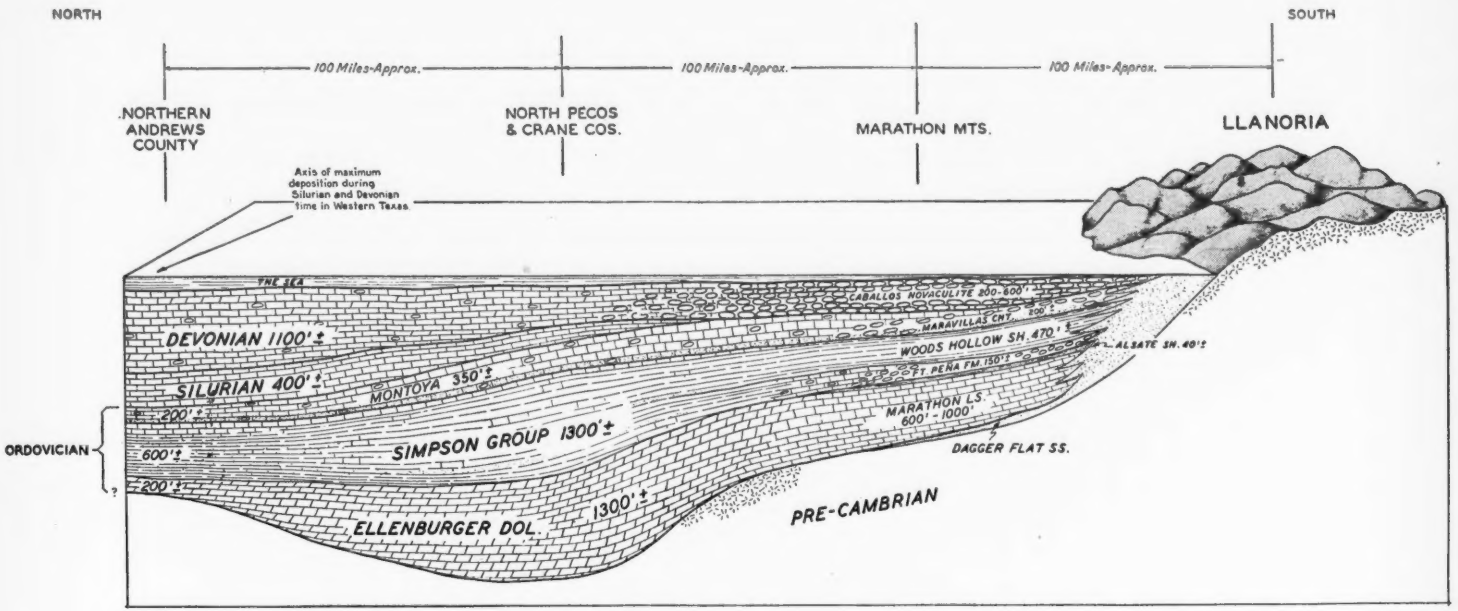
MISSISSIPPIAN

The Mississippian system is not represented in the Marathon Mountains[9] but it is present in the subsurface to the north. To date there have been two distinctive formations found in this system. The Woodford shale is the lower of these formations. It is dark brown shale with considerable evidence of vegetable matter, and it contains an abundance of *Sporangites*. Locally there are large developments of dark brown chert. In Andrews County the Woodford is 500± feet thick.

Above the Woodford shale is a siliceous cherty limestone bed 500± feet thick. For the present, this bed is referred to as the Mississippian limestone until a definite age can be given it.

The absence of Mississippian rocks in the Marathon region indicates to the writer that during the early part of Mississippian time deposition was taking place north of the Llanoria geosyncline in the so-called foreland (Fig. 5).

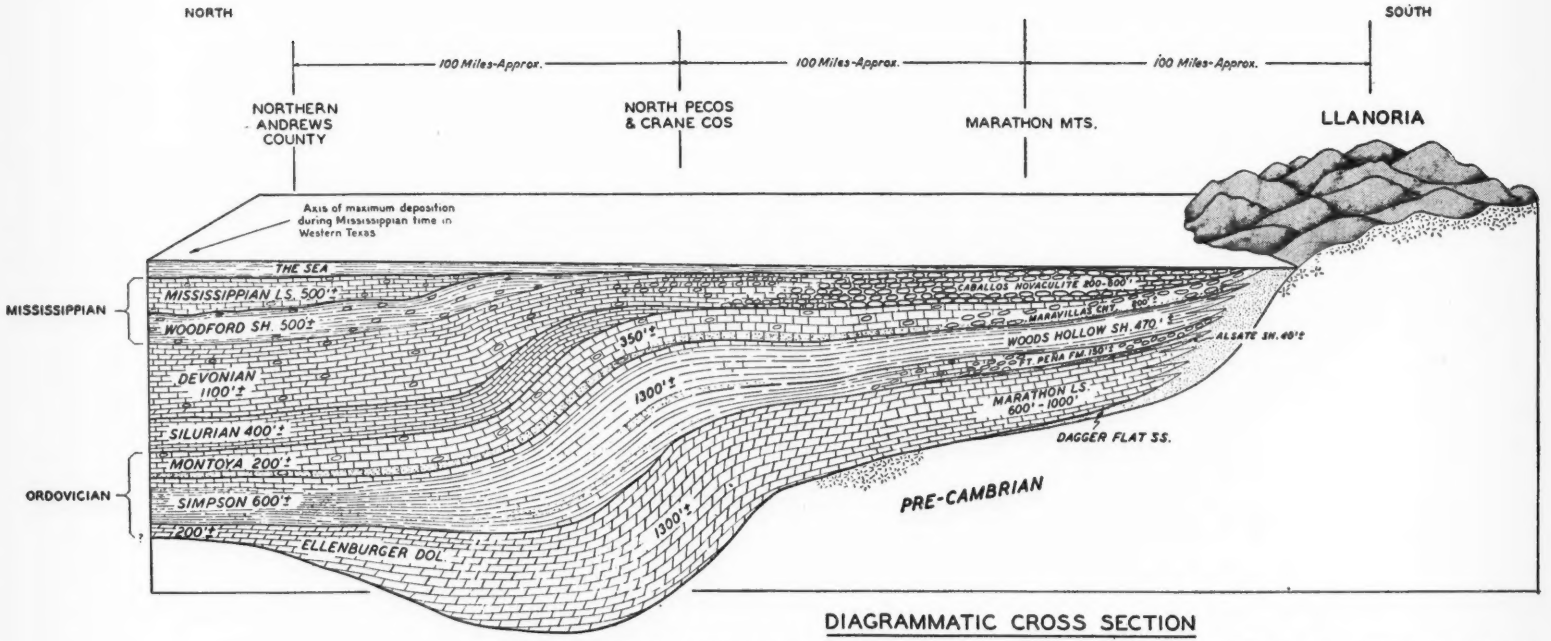
[9] Philip B. King, "Geology of the Marathon Region, Texas," *U. S. Geol. Survey Prof. Paper 187* (1937), p. 21.



DIAGRAMMATIC CROSS SECTION

PRE-PENNSYLVANIAN ROCKS AT CLOSE OF DEVONIAN PERIOD

FIG. 4



DIAGRAMMATIC CROSS SECTION

PRE-PENNSYLVANIAN ROCKS BEFORE LATE MISSISSIPPIAN DEFORMATION

FIG. 5

PENNSYLVANIAN

The Pennsylvanian system is represented in the Marathon and Ouachita mountains. There are 12,000±feet of Pennsylvanian rocks in the Marathon Mountains and 25,000±feet in the Ouachita Mountains. These rocks are coarse conglomerates, sandstones, and sandy shales. There was an extension of the Ouachita geosyncline into southern Oklahoma into which 17,000±feet of Pennsylvanian rocks were deposited. These were also of a very clastic nature, consisting of sandstones and shales. This extension has been named the Ardmore geosyncline.

The Tesnus formation in the Marathon Mountains is here considered as the lowest formation of the Pennsylvanian system and entirely Pennsylvanian in age. It has been suggested that the lower part of the Tesnus may be Missisppian in age.[10]

Outside of these deep troughs of clastic accumulations, thinner sections of Pennsylvanian rocks were deposited. These thinner sections are made up of limestones and finely textured shales. These are the foreland facies. The maximum thickness of the foreland facies in West Texas has not yet been determined. It is probably 3,000±feet.

Age of Llanoria Geosyncline

The Llanoria geosyncline began to be formed either at the end of Mississippian time or during late Mississippian time, according to the age assigned the Tesnus formation.

With the beginning of Tesnus deposition there is strong evidence that in a line parallel with and adjacent to, the front of the old Llanoria landmass a very deep trough began to form. Into this trough were dumped 12,000±feet of clastic Pennsylvanian rocks (Fig. 6). This trough is what may correctly be called the Llanoria geosyncline, and the Pennsylvanian rocks that were deposited in this trough may be referred to correctly as geosynclinal deposits. The Pennsylvanian rocks of the foreland are thinner and less clastic in nature, consisting largely of limestones and finely textured shales.

The writer feels that the obviously geosynclinal nature of the Pennsylvanian rocks in the Marathon and Ouachita mountains has caused workers to think and write of the pre-Pennsylvanian rocks as also geing geosynclinal deposits since they are clastic in nature.

Conclusions

1. The pre-Pennsylvanian rocks of the Marathon-Ouachita mountains are thinner than their equivalents north and west, with the exception of the Silurian of the Ouachita Mountains and possibly the Cambrian of the Marathon Mountains.

[10] E. H. Sellards, personal communication.

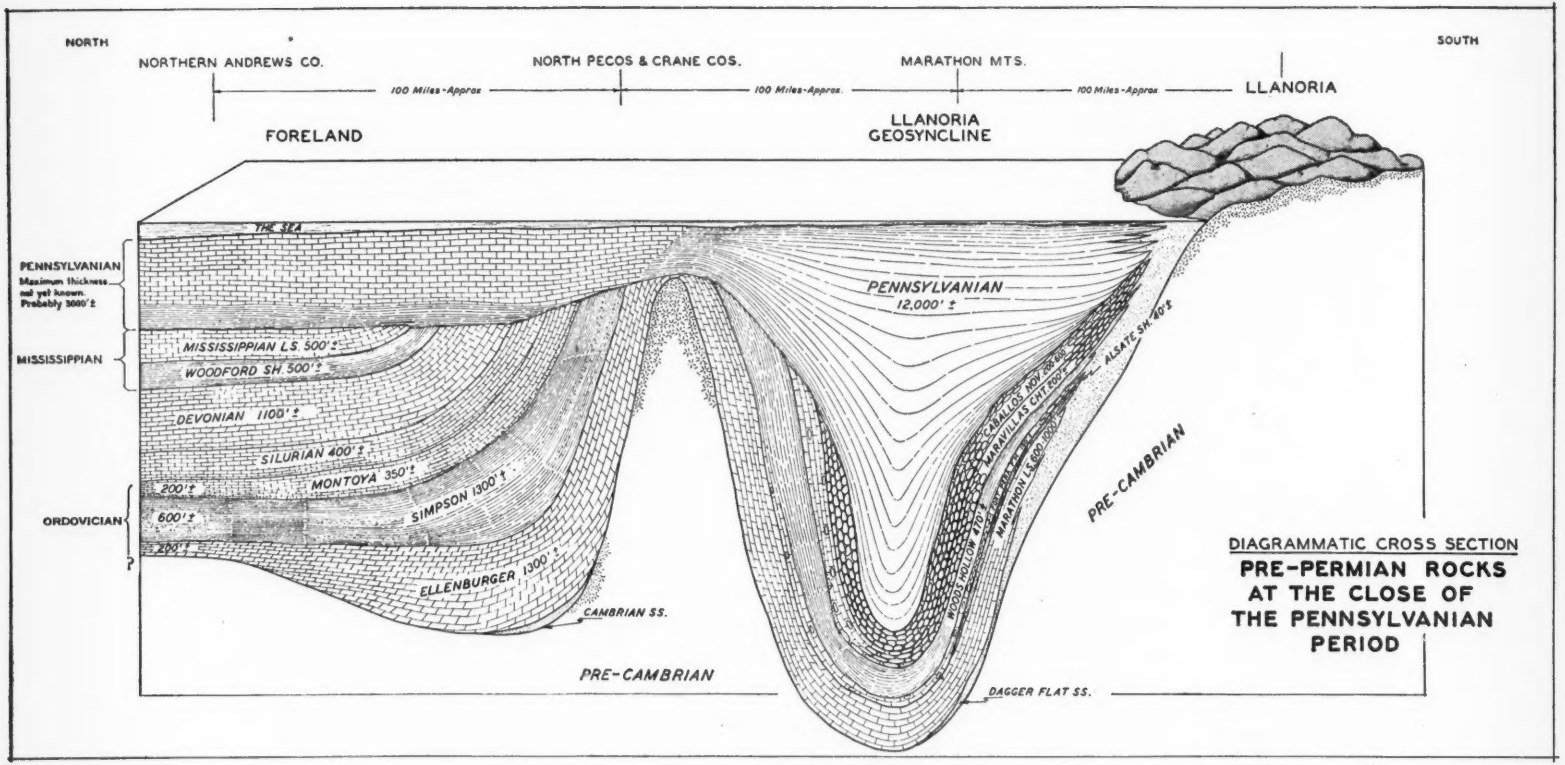

NORTH
SOUTH
NORTHERN ANDREWS CO.
NORTH PECOS & CRANE COS.
MARATHON MTS.
LLANORIA
100 Miles-Approx.
100 Miles-Approx.
100 Miles-Approx.
FORELAND
LLANORIA GEOSYNCLINE
THE SEA
PENNSYLVANIAN
Maximum thickness not yet known. Probably 3000'±
MISSISSIPPIAN
ORDOVICIAN
MISSISSIPPIAN LS. 500'±
WOODFORD SH. 500'±
DEVONIAN 1100'±
SILURIAN 400'±
MONTOYA 350'±
200'±
600'±
200'±
SIMPSON 1300'±
ELLENBURGER 1300'±
CAMBRIAN SS.
PRE-CAMBRIAN
PENNSYLVANIAN
12,000'±
CANALOS MDY. 2800'
MARVILLAS CHT. 700'
MARATHON LS. 600-1000'
WOODS HOLLOW 4700'
ALSATE SH. 40'±
PRE-CAMBRIAN
DAGGER FLAT SS.
DIAGRAMMATIC CROSS SECTION
PRE-PERMIAN ROCKS AT THE CLOSE OF THE PENNSYLVANIAN PERIOD

FIG. 6

2. The greatest amount of subsidence in pre-Pennsylvanian time in Texas and Oklahoma took place north and west of that area commonly referred to as the Llanoria geosyncline.

3. The Llanoria geosyncline, commonly defined as being a deep trough developed immediately in front of the Llanoria landmass, was not developed until the end of Mississippian time.

4. Only the Pennsylvanian sediments of the Marathon-Ouachita mountains can be correctly referred to as geosynclinal deposits if this geosyncline is pictured as a deep trough developed immediately in front of Llanoria.

5. The Llanoria geosyncline, if it is to be pictured as a deep trough developed immediately in front of Llanoria, should not be referred to as being present before the beginning of Pennsylvanian time.

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GEOLOGICAL NOTES

VERTICAL SOURCE IN OIL AND GAS ACCUMULATION[1]

JAMES H. GARDNER[2]
Tulsa, Oklahoma

By assuming some premise as true and then reasoning on a syllogistic basis to a conclusion is a stimulating exercise to say the least. The subject of the origin and accumulation of oil and gas being debatable means that anybody can enter the debate and take sides either *pro* or *con* on any theory; it is not necessary that he believe a premise to be a fact. The mere encouragement of new thought on the subject may be worthwhile and eventually be useful in opening the final door of truth.

There are various kinds of local structures in the oil and gas fields of the world. Geologists agree that the commercial deposits have been caught in some sort of a trap after having formerly had free movement, or at least are held in position by a trap at the time they are discovered. Beyond that statement there is a wide difference of opinion about the source and nature of the processes of origin and accumulation. Some geologists have different opinions at different times in their study and experience while others adopt an agnostic attitude and may form no opinions at all. Knowledge from authority as compared with experience and reason is not satisfactory because no authority has furnished a satisfactory answer.

The question of whether or not these hydrocarbon gases and fluids are organic in origin is itself debatable for the lack of proof. They may be of non-organic source with the proof yet to be discovered. Even though it is assumed, as is generally accepted, that they are organic in origin, is not this a secondary origin? The organic materials are from a non-organic source and thus, by going farther back it is seen that oil and gas have primarily originated from a non-organic or inorganic source. For example, the process of photosynthesis by chlorophyl in plant life converts carbon dioxide and water into a combination of hydrogen and carbon to produce organic substance. The primary source of carbon dioxide and water is inorganic. Photosynthesis is a bridge that crosses between the inorganic and the organic world. Possibly oil and gas have never crossed this bridge at all. They may have arisen from original non-organic elements. The function of catalysts is mysterious. Possibly there is an unknown factor in the process which may be described as the figure X. Some wells produce carbon dioxide instead of natural gas. In such cases the factor X may have been missing. Other wells produce helium gas for some reason that suggests a deep-seated source from

[1] Manuscript received, June 23, 1945.

[2] Gardner Petroleum Company.

beneath the sedimentary section. Oil and gas may have originated primarily from carbon dioxide and water by circumvention of photosythesis.

Let us here assume for the sake of argument that any specific oil or gas field has accumulated these substances from a source more or less directly below the trap; that the source is from a greater depth and from a zone of once higher pressure than is now present in the trap; furthermore, that there have frequently been leaks to shallower sands in a series of vertical stages involving time, pressure, and position of the accumulations.

The loss of circulation in rotary-drilling wells, the sudden loss of pump pressure in water-flooding, the loss of acid in acidizing under pressure, and the loss of pressure in water-disposal wells when filled with fluid above hydrostatic head, all indicate ready movement of liquids under excess of pressure. More pressure finds more permeability through either tight fractures (jointing) or porosity. When the pressure is released the effective permeability seems to shut off again like a check-valve.

In vertical accumulation of oil and gas some such process as here suggested may have taken place. If the carrier beds were originally filled with water under hydrostatic pressure, or partially so filled, the excess pressure accompanying oil and gas from a greater depth could rise vertically into the pre-existing trap and push the water back to the sides of the trap in whatever carrier beds were suitably located and capped off to receive them. Recession of excess pressure would shut off circulation and result in establishing equilibrium on a hydrostatic basis. Possibly only the deep sands first received accumulation, and at some later period of dynamics a way was opened for cross-migration to shallower beds. This might occur especially on structures of local uplift along faults and domes. The Garber oil field in Oklahoma is a classical case wherein fourteen sands, or nearly all the sands from Arbuckle limestone up to and including shallow Permian beds, contain commercially productive oil. The quality of oil is of a similar high-grade character in all of them. Cross-migration is obvious at Garber and a deep source is indicated, as has frequently been pointed out. There is much post-Permian uplift on the Garber dome to permit of cross-fracturing. Loss of circulation in drilling was common there. In the same general area, however, there are other buried islands, like the Ramsey dome, where there has been very little post-Permian folding. The effective folding there is largely pre-Pennsylvanian in age. The oil accumulation is also essentially all pre-Pennsylvanian at Ramsey. Some traps may have once contained commercial oil or gas pools and at a later stage the accumulations found their way to the surface and were dissipated with only salt-water seepages or showings of oil and gas being present. Seemingly, some traps with showings should be oil pools except for the presence of such conditions. Most of the accumulations are thoroughly sealed off from surface escape but may contain deep fractures in the strata. Some of them may never have had accumulation at all because they did not coincide with a locus of origin. The theory that such traps are too young in age to have caught accumulation is

quite unsatisfactory because others equally young do contain accumulation. In barren structures there is apparently something that failed in local source of oil and gas. Long-distance migration horizontally through the strata would have hit them with a bang. The same is true for numerous good stratigraphic traps that fail to produce. It seems that any form of trap must coincide with some form of local source of oil and gas to produce. In this connection it is interesting to observe the prevailing rule that producing stratigraphic traps are under, or on, the sides of local uplifts. This fact indicates that the local folding is in some way related to the source of the accumulation, and it looks like a source from beneath the structure. Many good stratigraphic traps by pinch-out updip have all the mechanics for gathering oil but on normal slope fail to show oil or gas pools. Does deep-seated fracturing at local spots have something to do with accumulation?

Deep drilling in recent years has seemingly indicated that gas is more common than oil in the deep strata and that with increased depths this trend will continue. The conclusion is reasonable and there are physical factors of pressure and temperature to make such theory plausible. On the other hand, it may eventuate that oil will be found in greater quantity at still deeper levels below the deep gas fields to upset the rule. Should that be proved, then the old rule that many shallow gas fields have shallow oil fields beneath them will be extended to deep gas fields also having deep oil fields beneath them. Gas may accumulate more easily upward across the strata than oil so that its occurrence in the oil-producing areas even at deep levels may be proved a forerunner of oil at still greater depths.

Regardless of the form of the producing trap, it may be that the source from which it drew is at a greater depth, more or less directly under the point where the field is located. In barren traps the source of origin and accumulation may not have been tapped from its deep levels or may not have been present at such points. But a producing trap apparently coincides with local source whether it be helium, carbon dioxide, natural gas, or petroleum.

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DISCUSSION

The Discussion Department provides a means for the publication of correction or pertinent discussion of subject matter previously printed in the *Bulletin*, or other matters of interest.

CIVIL SERVICE RESOLUTION[1]

J. EDMUND EATON[2]
Los Angeles, California

The May, 1945, *Bulletin* reports the adoption in business meeting of a Civil Service resolution[3] protesting United States Civil Service Commission Announcement No. 343, which latter advises that the Commission will accept either experience or academic study in certain War Service Appointments as Geologist. This rather inclusive resolution cites the full membership, 4326, of the Association, thereby implying that I approve of it.

The general membership of the Association, including myself, was unable to vote on this resolution. I wish to convey my dissent, and to express my individual belief that demonstrated knowledge and ability should be recognized regardless of how obtained, without prejudice toward their source.

I am in accord with that part of the resolution which holds that qualifications tend to be ascertained more reliably through written than through oral tests. Had the resolution been restricted to this thesis it is believed that it would have been constructive. Instead, it goes on to compromise its position by adding the theory that a particular method of training is necessary.

The most unfortunate part of the resolution is its claim[4] that *conventional* training is necessary in science. The validity of this claim is refuted by the standing of such scientists as Edison,[5] Schuchert,[6] and countless others that could be named, and I, for one, reject it utterly.

The authority of the business meeting to represent the Association in business matters is not questioned by me. The particular resolution, however, also involves the question of whether knowledge and ability shall be recognized regardless of how obtained, or only when obtained through conventional training. Each individual member must decide such a question for himself. It is therefore believed that the resolution, proposed and adopted with the same sincerity that actuated the Civil Service Announcement, should not have cited the full membership in the absence of a full vote with the proportion of yeas and nays stated.

[1] Manuscript received, June 4, 1945.

[2] Consulting geologist, 2062 North Sycamore Avenue.

[3] "Minutes, Thirtieth Annual Business Meeting, Mayo Hotel, Tulsa, Oklahoma, March 27, 1945," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 5 (May, 1945), p. 574.

[4] *Op. cit.*, p. 574, par. 7, line 3.

[5] Thomas Alva Edison: "His [conventional] education was limited to 3 months in the Public School of Port Huron, Mich.," *Encyclopaedia Britannica*, Fourteenth Edition, Vol. 7, p. 961.

[6] Charles Schuchert, Prof. of Paleontology, 1904–23, Yale Univ.; Prof. Emeritus, 1923–42, Yale Univ.; President, Paleontological Soc., 1910; President, Geol. Soc. Amer., 1922: "Public schools," *American Men of Science* (1927).

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

THE GEOLOGICAL RESULTS OF THE SEARCH FOR OILFIELDS IN GREAT BRITAIN, BY G. M. LEES AND A. H. TAITT

REVIEW BY BURTON WALLACE COLLINS[1]
Auckland, New Zealand

"The Geological Results of the Search for Oilfields in Great Britain," by George Martin Lees and Alfred Harold Taitt. *Abstracts of Proceedings Geol. Soc. London*, No. 1408 (December 29, 1944), pp. 14–16 (with "Discussion," pp. 16–19).

Tantalizing references to "Britain's New Oilfield" have appeared from time to time in the local newspapers; now the first authoritative account has reached the writer. It is unfortunately in very abbreviated form, but probably by the time this review is printed, or soon after, the full account together with illustrations will have been published in the *Quarterly Journal of the Geological Society of London*, and those interested will be able to consult the full paper for further information.

Although so brief, this abstract of the paper presented by Lees and Taitt to the Geological Society contains a surprising amount of both factual matter and opinion, and the report of the ensuing discussion is also enlightening.

"The Geological Basis of the Present Search for Oil in Great Britain by the D'Arcy Exploration Company, Limited" is the title of a paper by Dr. Lees and Percy Thomas Cox (the latter, by the way, is a New Zealander), which was published in the *Q.J.G.S.*, Vol. 93, Pt. 2 (June 29, 1937), pp. 156–94, and which, besides giving the geological background, describes the results obtained up to March of the year of publication. The present paper continues the story up to September 1944.

The following quotations from the abstract give the salient points so far made public.

. . . an analysis of colliery data and coal exploration borings afforded grounds for expecting an anticlinal axis at Eakring, Nottinghamshire, and this expectation was confirmed by seismic reflection and refraction surveys. A well was located at Eakring as a result and on 19 June 1939, oil was struck in the Rough Rock sandstone of the Millstone Grit Series. On test the well proved capable of a production of 12 tons per day.

[On] the outbreak of war . . . it was decided to concentrate all drilling effort on oil production and on exploration in the immediate vicinity of Eakring, at the expense of various scattered projects which had been contemplated elsewhere in the country. . . . The total oil production up to the end of September 1944 is 317,612 tons.

In summary, the drilling results to date have been:

		Total footage
EXPLORATION BORINGS		
Shallow holes for structural information	43	28,804
Unsuccessful test wells	52	166,427
PRODUCTION BORINGS		
Total deep wells drilled	253	558,798
Number successful	237	—
Shallow wells in Formby area	45	12,489
Number successful in Formby area	19	—
		766,518

. . . In addition to oilfield discovery, . . . [the exploration borings] have revealed extensive areas of coal seams to the east and south-east of Lincoln at depths of about 4000 feet. The boring at Aislaby

[1] P.O. Box 10, Auckland CI. Manuscript mailed, April 26, 1945; received, June 25, 1945.

in Eskdale proved a Permian evaporite series between 3656 and 4773 feet in which zones of sylvinite and polyhalite occur, indicating an extension of the Zechstein potash basin of North-West Germany into northern Yorkshire. [Newspaper reports state that the potash deposits, the first to be discovered in Britain, will be exploited after the war.—B.W.C.]

Some reference is also made to the important part played by seismic surveys in the exploration program, and in this connection some remarks made by Dr. Lees in his reply to the discussion of the paper are especially interesting:

> The refraction arc method used in the seismic surveys was an adaptation of a technique evolved in Persia, but it had not been expected at the outset that it could be used for such accurate work. The plan had been to use the refraction arcs as a scouting method and to follow up with a reflection survey of selected anticlines on which drilling locations would be chosen. Unfortunately, conditions had proved unsuitable for reflection work and after several trials in different areas this method had been abandoned and the refraction method used for both reconnaissance and detail. It was an outstanding achievement that it had been possible to construct the structural contour map . . . with an accuracy that had stood the test of a large number of borings.

Two short paragraphs only are devoted to remarks on new stratigraphic and structural evidence brought to light by the borings, but in the discussion the president of the Geological Society (Professor W. G. Fearnsides) stated that, "Never before had so much exact and new information about the underground geology of Britain been presented to the Society. . . ." The full paper, when published, should, therefore, be well worth reading.

With regard to the oil possibilities of Great Britain, the authors conclude that:

> . . . the best prospects of oil discovery are in the Millstone Grit or the Carboniferous Limestone, but the possibility of oil in older formations is not excluded. The Silurian of the Welsh Border country contains numerous oil indications as solid or semi-solid bitumen, and oil encountered in the Devonian in a boring at Willesden may have its origin in the Silurian or, alternatively, it may have been generated in the Devonian itself, here in a zone of transition between "Old Red" and marine conditions.

One may, in conclusion, echo the sentiments expressed by one of the contributors to the discussion, who "remarked on the great value to stratigraphy of the enlightened policy of the authors and the D'Arcy Exploration Company, which had led them to make public at so early a stage the results of the seismic and geological work of the Company."

A DEEP BORE IN THE CLEVELAND HILLS, BY A. FOWLER

REVIEW BY BURTON WALLACE COLLINS[1]
Auckland, New Zealand

"A Deep Bore in the Cleveland Hills," by A. Fowler. *Geol. Mag.*, Vol. 81, No. 5 (October, 1944), pp. 193–206; and No. 6 (December, 1944), pp. 254–65.

In this recent paper describing stratigraphical results of boring for oil in England, the author describes in detail the "fine record" of Upper Paleozoic strata penetrated in a rotary bore put down by the Gulf Exploration Company (Great Britain), Limited—of particular interest because the site of the well is remote from known outcrops of these rocks. Cores were taken at selected points, and although there was no more than 200 feet of useful cores—as the author remarks, a mere fragment in 6283 feet of strata—yet they proved very valuable in unravelling problems of stratigraphy and correlation. It is surprising, "not that we know so little, but rather that we know so much."

[1] P.O. Box 10, Auckland CI. Manuscript received, June 25, 1945.

Briefly, the section penetrated was as follows.

Estuarine series	Lower	230 feet
Lias	Upper	190
	Middle	130
	Lower	750
Trias	Rhaetic	34
	Keuper marls	686
	Bunter sandstone	900
Permo-Triassic		272
Permian		648
Carboniferuos (part)		2443
	Total depth	6283 feet

NOTES ON THE GEOLOGY OF THE SOUTHERN ROUMANIAN OIL DISTRICT, BY J. F. M. DE RAAF

REVIEW BY BURTON WALLACE COLLINS[1]
Auckland, New Zealand

"Notes on the Geology of the Southern Roumanian Oil District, with Special Reference to the Occurrence of a Sedimentary Laccolith," by Johan Ferdinand Maurits de Raaf. *Abstracts of Proceedings Geol. Soc. London*, No. 1407 (November 29, 1944), pp. 2, 3 (with "Discussion," pp. 3–6).

Three types of "salt-plugs" in Roumania are recognized by the author of this paper.

(1) Normal salt-plugs, "generally located in the core of individual folds," which "cause a certain amount of dragging up and piercing of the strata." The main phase of this "diapirism" is stated to be of post-Pliocene age. This type is "difficult to compare with any type of igneous intrusion."

(2) Salt intrusions which "took place along pre-existing strike-faults (thrust-faults) and cross-faults," showing "striking morphological similarities with igneous dykes."

(3) "Sedimentary intrusions, in general shape comparable with the igneous laccolith." In one example of this type a "clayey salt-breccia" began to penetrate upper Miocene beds "along partings of strata, splitting the formation open. Subsequently, however, the original purely accordant character of the intrusion was locally somewhat obliterated by a breaking up of the invaded formation along the zone of contact with the intruding clayey breccia. This has given rise to phenomena recalling Daly's magmatic stoping. . . . The process of injection of the salt-breccia is believed to be connected with upward movement of deeper-seated rock-salt."

During the discussion of this paper several speakers referred to the possible bearing of fuller knowledge of salt tectonics on the question of the age of the "Saline Series" of the Salt Range of the Punjab, India; and one (C. S. Middlemiss) stated: "It may also be that the connection between salt-plugs and domes and the presence of oil may not be without significance in future oil researches in the neighbourhood of the Saline Series."

Professor V. C. Illing said that, judging by the German examples of salt movement, in regions of folded rocks the salt tended to have a linear development in the earlier phases, probably because the movement followed anticlinal crests or fault fissures. It appeared that "the farther the salt travelled from its source of origin the more it tended to depart from these earlier linear arrangements and to become more focal and plug-like."

Another speaker (A. Reid) mentioned seeing, on a visit to the Roumanian oil fields, "a well sunk to the astonishing depth of 1475 metres in the short period of a fortnight."

[1] P.O. Box 10, Auckland, CI. Manuscript mailed, April 26, 1945; received, June 25, 1945.

A RÉSUMÉ OF THE PALEOZOIC STRATIGRAPHY OF COLORADO, BY J. HARLAN JOHNSON

*"A Résumé of the Paleozoic Stratigraphy of Colorado," by J. Harlan Johnson, associate professor of geology, Colorado School of Mines. *Quar. Colorado Sch. Mines*, Vol. 40, No. 3 (Golden, July, 1945). 109 pp., 10 tables, 2 pls., 17 figs. Price, $2.00.

Dr. Johnson reports on the older sedimentary formations of Colorado that are attracting much of the attention of the oil men of the United States. It is in these formations that oil and gas occur at Rangely and in other fields. There are also promising possibilities that these formations will produce commercially important quantities of oil in other sections of the state, including the plains area of eastern Colorado.

Furthermore, it is in these formations that some of the most prolific ore deposits are found in the mountainous sections of the state. A greater knowledge of these formations may assist in prospecting for additional deposits.

Numerous photographs, diagrams, geologic sections, tables, and an extensive bibliography add to the publication's value and utility. It may be obtained from the Department of Publications, Colorado School of Mines, Golden, Colorado, at $2.00 a copy.

RECENT PUBLICATIONS

ALBERTA

*"Bituminous Sands of Alberta," by K. A. Clark. *Oil Weekly*, Vol. 118, No. 11 (Houston, August 13, 1945), pp. 46–51; index map and 3 photographs.

APPALACHIAN REGION

*"The Stones River Equivalents in Appalachian Region," by Byron N. Cooper. *Jour. Geol.*, Vol. 53, No. 4 (Chicago, July, 1945), pp. 262–75; 3 figs., 1 table.

ARGENTINA

*"El factor estructural en las acumulaciones petroliferas del pais" (Structural Factor in Petroleum Accumulations), by Osvaldo Barcaccini. *Bol. Inform. Petroleras*, Vol. 22, No. 247 (Buenos Aires, March, 1945), pp. 12–29; 15 figs. In Spanish.

ASIA

"Early Man and Pleistocene Stratigraphy in Southern and Eastern Asia," by Hallam L. Movius, Jr. *Peabody Museum, Harvard Univ. Papers*, Vol. 19, No. 3 (1944). 113 pp., 47 figs., 6 tables. Reviewed by Kirk Bryan in *Amer. Jour. Sci.*, Vol. 243, No. 8 (New Haven, Connecticut, August, 1945), pp. 469–70.

BOHEMIA

*"The Late Carboniferous Vertebrate Fauna of Kounova (Bohemia) Compared with That of the Texas Red Beds," by Alfred Sherwood Romer. *Amer. Jour. Sci.*, Vol. 243, No. 8 (New Haven, Connecticut, August, 1945), pp. 417–42.

BRITISH GUIANA

*"Report on Exploration for Oil in British Guiana," by H. G. Kugler, S. C. Mackenzie, R. M. Stainforth, J. C. Griffiths, and G. R. Brotherhood. *Geol. Survey of British Guiana Bull. 20* (1944). 78 pp. Envelope of 10 folded sheets (maps, sketches, logs, graphs, curves, sections). Printed in Georgetown, Demerara. Price, $1.00.

CALIFORNIA

"Paleocene and Eocene Stratigraphy of the Northwestern Santa Ana Mountains, Orange County, California," by W. P. Woodring and W. P. Popenoe. *U. S. Geol. Survey Prelim. Chart 12*, Oil and Gas Investig. Ser. (July, 1945). Sheet, 31×41 inches, contains 6 graphic stratigraphic sections on vertical scale of 1 inch equals 150 feet, a generalized geologic map of Los Angeles basin, and a map of northwestern part of Santa Ana Mountains. Obtainable from Director, U. S. Geol. Survey, Washington 25, D. C., and Room 533, U. S. Post Office and Courthouse Building, Los Angeles, California. Price, $0.40.

COLORADO

"Selected Bibliography on Colorado Petroleum Geology and Stratigraphy," by J. Harlan Johnson. *Mines Magazine*, Vol. 35, No. 4 (Golden, April, 1945), pp. 167–73.

*"A Résumé of the Paleozoic Stratigraphy of Colorado," by J. Harlan Johnson. *Colorado School of Mines Quarterly*, Vol. 40, No. 3 (Golden, July, 1945). 109 pp., 10 tables, 2 pls., 17 figs. Price, $2.00.

ENGLAND

*"A Section in the Lower London Tertiaries in Ballards Way, Croydon, Survey," by F. Gossling. *Proc. Geologists' Assoc.*, Vol. 56, Pt. 2 (London, June 29, 1945), pp. 135–38; 1 fig.

FLORIDA

*"Salt Water Encroachment in Limestone at Silver Bluff, Miami, Florida," by Russell H. Brown and Garald G. Parker. *Econ. Geol.*, Vol. 40, No. 4 (Urbana, Illinois, June–July, 1945), pp. 235–62; 14 figs.

GENERAL

*"Diagnostic Characteristics of Crude Oil: Fluorescence Analysis in Ultra-Violet Light," by J. N. Mukherjee and M. K. Indra. *Jour. Inst. Petroleum*, Vol. 31, No. 258 (London, June, 1945), pp. 173–78.

*"The Primary and Secondary Elements of a Fold," by John Challinor. *Proc. Geologists' Assoc.*, Vol. 56, Pt. 2 (London, June 29, 1945), pp. 82–88; 3 figs.

*"Geology in Embryo (Up to 1600 A.D.)," by C. E. N. Bromehead. *Ibid.*, pp. 89–134.

*"Significance of Declining Productivity Index, " by C. V. Millikan and Herbert F. Beardmore. *Petrol. Tech.*, Vol. 8, No. 4 (New York, July, 1945). 10 pp., 9 figs. *A.I.M.E. Tech. Pub. 1872.*

*"Fractional Analysis of Well Effluents to Trace Migration of High-Pressure Reservoir Gas," by E. P. Valby. *Ibid.*, 7 pp., 3 figs. *A.I.M.E. Tech. Pub. 1873.*

*"Behavior and Control of Natural Water-Drive Reservoirs," by George R. Elliott. *Ibid.* 17 pp., 11 figs. *A.I.M.E. Tech. Pub. 1880.*

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*"Marine Petroleum Possibilities," by Henry Emmett Gross. *Petrol. Engineer*, Vol. 16, No. 11 (Dallas, July, 1945), pp. 76–82; 3 figs.

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*"Present Status of Geochemical Prospecting," by V. G. Gabriel. *Oil Weekly*, Vol. 118, No. 10 (Houston, August 6, 1945), pp. 50–53; 1 table.

*"Climatic Maps of Geologic Interest," by S. S. Visher. *Bull. Geol. Soc. America*, Vol. 56, No. 7 (New York, July, 1945), pp. 713–36; 30 figs.

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INDIA

"Symposium on the Age of the Saline Series in the Salt Range of the Punjab," by 14 authors. *Proc. Natl. Acad. Sci. India 1944*, Vol. 14, Pt. 6, Sec. B (May, 1945), pp. i–xxxii and 205–334. Symposium held at Poona, December, 1944, under joint auspices of National Academy and the Indian Academy of Sciences. Separate copies of this number of the *Proceedings*, containing the following articles, may be had from the General Secretary, National Academy of Sciences, c/o Department of Botany and Geology, University of Lucknow, U.P., India, at the price of Rs. 4/8 (India), Rs. 5 (foreign), postpaid.

Microfossils and Problems of Salt Range Geology (presidential address), by B. Sahni
Note on the Age of the Salt Marl, by F. R. C. Reed (Cambridge)
The Age of the Saline Series of the Punjab Salt Range, by E. H. Pascoe (Harpenden)
A Note on the Repeated Overthrusts of the Cambrian Rocks on the Eocene, by D. N. Wadia (Colombo)
The Age of the Saline Series in the Salt Range of the Punjab, by B. S. Lamba (Khewra)
Age and Origin of the Salt Deposits of North-West India, by L. M. Davies (Edinburgh)
A Second Contribution to the Geology of the Punjab Salt Range, by C. S. Fox (Calcutta)
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The Occurrence of Bitumen in the Punjab Salt Range and Kohat Areas and Its Bearing on the Age of the Saline Series, by A. Lahiri (Farnborough)

JAPAN

Japan, a Physical, Cultural, and Regional Geography, by Glenn Thomas Trewartha. xv+607 pp., 281 figs. Univ. Wisconsin Press, Madison (1945). Price, $5.00. Reviewed by Ellsworth Huntington in *Amer. Jour. Sci.*, Vol. 243, No. 8 (New Haven, Connecticut, August, 1945), pp. 470–72.

KENTUCKY

*"Geology and Mineral Resources of the Jackson Purchase Region, Kentucky," by Joseph K. Roberts and Benjamin Gildersleeve. Contains a discussion, "Paleozoic Geology," by Louise Barton Freeman. *Kentucky Dept. Mines and Minerals, Geol. Div., Bull. 8*, Ser. 8 (Lexington, 1945). Published in cooperation with the Tennessee Valley Authority. 126 pp., 21 figs., map, and chart.

LOUISIANA

"The Eocene, Oligocene, and Lower Miocene Series," *Progress Report of the Geological*

Names and Correlations Committee, 1944–1945, South Louisiana Geological Society (1945). 4 multigraphed pages, including a table "Proposed Stratigraphic Column." Envelope contains 10 correlation sections and an index map of southern Louisiana (blue-line prints). Chairman of the committee, W. R. Canada, Magnolia Petroleum Company, 517 Weber Building, Lake Charles, Louisiana. Price, $3.00.

MONTANA

"Mississippian and Devonian Stratigraphy of Northwestern Montana," by Laurence L. Sloss and Wilson M. Laird. *U. S. Geol. Survey Prelim. Chart 15*, Oil and Gas Investig. Ser. (August, 1945). Sheet, 30×35 inches. 13 stratigraphic sections, index map, correlation diagram, and brief text. For sale by Director, Geological Survey, Washington 25, D. C.; 303 North 27th Street, Billings, Montana; Federal Building, Casper, Wyoming; 314 Boston Building, Denver, Colorado; 234 Federal Building, Tulsa, Oklahoma.

NEVADA

"Geologic Reconnaissance of Arden Area, Clark County, Nevada," by J. C. Miller. *U. S. Geol. Survey* (1945). "The character and altered condition of the underlying sedimentary rocks are unfavorable for the occurrence of oil and gas in commercial quantities." Report is accompanied by a geologic map on a scale of 1 inch equals 1 mile, and a columnar section. Not available for distribution, but copies may be consulted in the offices of the Survey at Washington, D. C.; 8 Federal Building, Las Vegas, Nevada; 533 Post Office and Court House Building, Los Angeles, California; and 306 Federal Building, Salt Lake City, Utah.

NEW MEXICO

*"Devonian of New Mexico," by Frank V. Stevenson. *Jour. Geol.*, Vo.. 53, No. 4 (Chicago, July, 1945), pp. 217–45; 13 figs.

NEW YORK

*"Use of Microlithologies as Illustrated by Some New York Sedimentary Rocks," by Harold L. Alling. *Bull. Geol. Soc. America*, Vol. 56, No. 7 (New York, July, 1945), pp. 737–56, 6 figs.

TEXAS

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TRINIDAD

*"Analysis of Trinidad Crude Oils. Part II—Paraffinic Oils," by F. Morton and A. R. Richards. *Journ. Inst. Petroleum*, Vol. 31, No. 258 (London, June, 1945), pp. 159–72; 3 tables, 14 figs.

*"The Foraminifera of the Cipero Marl Formation of Trinidad, British West Indies," by Joseph A. Cushman and R. M. Stainforth. *Cushman Lab. Foram. Research Spec. Pub. 14* (Sharon, Massachusetts, April 21, 1945). 75 pp., 16 pls. of fossils. Price, $1.50, postpaid.

WYOMING

"Stratigraphic sections and Thickness Maps of Jurassic Rocks in Central Wyoming," by J. D. Love, Henry A. Tourtelot, Chester O. Johnson, H. H. R. Sharkey, Raymond M. Thompson, and A. D. Zapp. *U. S. Geol. Survey Prelim. Chart 14*, Oil and Gas Investig. Ser. (August, 1945). Single sheet, 39½×64 inches. 3 series of stratigraphic sections and 5 maps, with brief text, index maps, and tables. For sale by Director, Geological Survey, Washington 25, D. C.; Federal Building, Casper, Wyoming; 314 Boston Building, Denver, Colorado; and 234 Federal Building, Tulsa, Oklahoma. Price, $0.40.

WYOMING-MONTANA

*"Wyoming. Part 2, Oil and Gas Prospects," by Pierre La Fleiche. *Oil Weekly*, Vol. 118, No. 8 (Houston, July 23, 1945), pp. 46–50; map and cross section.

"Structure Contour Map of the Powder River Basin, Wyoming and Montana," by William G. Pierce and Roselle M. Girard. *U. S. Geol. Survey Prelim. Map 33*, Oil and Gas Investig. Ser. (August, 1945). Sheet 44×56 inches. Scale of map, 1 inch equals 4 miles. Contour interval, 200 feet. May be purchased from Director of the Geological Survey, Washington 25, D. C.; Room 234, Federal Building, Tulsa, Oklahoma; Room 314, Boston Building, Denver, Colorado; Federal Building, Casper Wyoming; 313 North 27th Street, Billings, Montana.

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**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 19, No. 4 (July, 1945)

"Some New Genera of the Bellerophontacea," by J. Brookes Knight

"Late Paleozoic Ammonoids from the Chinati Mountains of West Texas," by A. K. Miller

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"Two New Ostracoda from Subsurface, Cook Mountain (Eocene) Strata of Texas," by Morton B. Stephenson

"Kinkaid Corals from Illinois," by William H. Easton

"Procedure of Simplified Stereophotography of Fossils," by Preston F. Gott

"Bibliography and Index to New Genera, Species and Varieties of Foraminifera for the Year 1942," by Hans E. Thalmann

* *Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 15, No. 2 (August, 1945).

"Entrapment of Air in Beach Sand," by K. O. Emery

"Triassic Sediments in West Texas and Eastern New Mexico," by Raymond Sidwell

"Calcite Oolites or 'Cave Pearls' Found in the 'Cave of the Mounds'," by Alonzo W. Pond

"The Rounding of Sand Grains," by W. H. Twenhofel

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‖Craig, Ross Walter, Stanolind Oil & Gas Co., Box 40, Casper, Wyo.
‖Creed, James Gordon, L. W. Frankley, 544 Roosevelt Bldg., Los Angeles, Calif.
Cunningham, Benjamin A., Jr., Republic National Bank of Dallas, Box 5961, Dallas, Tex.
Curry, H. Donald, Shell Oil Co. of Canada, 302 Bank of Toronto Bldg., Calgary, Alta., Canada
Dawson, William Aubrey, Skelly Oil Co., 510 Petroleum Bldg., Wichita, Kan.
‖Devlin, Frank, The Atlantic Refining Co., Tower Bldg., Jackson, Miss.
‖Dickson, Dorothy MacGregor, Union Producing Co., Box 2492, Houston, Tex.
‖Dietz, Robert Sinclair, 305 Indiana, Urbana, Ill.
‖Dillon, Edward Cunningham, Gulf Oil Corp., Box 2100, Houston, Tex.
Diven, Quay S., Tide Water Associated Oil Co., 888 Pacific Electric Bldg., Los Angeles, Calif.
Dix, Charles Hewitt, United Geophysical Co., 595 E. Colorado, Pasadena, Calif.
‖Dodd, James Grady, Humble Oil & Refining Co., Box 2180, Houston, Tex.
Drake, Nels D'Arcy, Standard Oil Co. of New Jersey, Room 1626, 30 Rockefeller Plaza, New York, N. Y.
Drennan, William Alvin, Western Geophysical Co., 711 Edison Bldg., Los Angeles, Calif.
Dunlap, Robert Craig, Geophysical Service, Inc., Box 808, Everett, Wash.
‖Durr, John Frendberg, Belle Fourche, S. Dak.
Eargle, Dolan Hoye, U. S. Goleogical Survey, Box 223, Tuscaloosa, Ala.
‖Elliott, Elizabeth Anne, Gulf Oil Corp., Box 1150, Midland, Tex.
Erickson, Earling Lester, Continental Oil Co., 700 Edison Bldg., Los Angeles, Calif.
Evans, Ralph, Standard Oil Co. of Texas, 347 Milam Bldg., San Antonio, Tex.
Feldmiller, Charles Henry, Equitable Gas Co., Pittsburgh, Pa.
Ferris, Craig, E. V. McCollum & Co., Thompson Bldg., Tulsa, Okla.
‖Finch, Kenneth Day, Schlumberger Well Surveying Corp., Box 92, Shreveport, La.
‖Fisher, Arnold J., Skelly Oil Co., Midland, Tex.
Ford, Robert Davis, Schlumberger Well Surveying Corp., Long Beach, Calif.
Foster, Fred K., The Chicago Corp., 209 Ardis Bldg., Shreveport, La.
‖French, Harvey F., 1295 S. Odgen St., Denver, Colo.
Frey, Maurice Gordon, The California Co., 1006 U. S. Natl. Bank Bldg., Denver, Colo.
Frost, Victor LeRoy, The Ohio Oil Co., Thompson Bldg., Tulsa, Okla.
Fruehling, Siegfried Williams, Seismograph Service Corp., 709 Kennedy Bldg., Tulsa, Okla.
‖Gagnebin, Elie A., Laboratoire de Geologie, Universite, Lausanne, Switzerland
‖Gester, Peter Warren, Richmond Exploration Co., Apt. 93, Maracaibo, Venezuela, S. A.
Gibson, Lee Wilbur, Humble Oil & Refining Co., Box 2180, Houston, Tex.
‖Gilbert, Edward Everett, Sun Oil Co., Box 186, Bassano, Alta., Canada
Gilbert, James Cornelius, Barnsdall Oil Co., Box 1061, Cody, Wyo.

‖Graf, Donald Lee, Rt. 1, Elma, Iowa
Graser, Frederick Arthur, consulting, 840 E. Thirty-seventh St., Long Beach, Calif.
Gravelle, Kenneth Allen, Gulf Refining Co., Box 811, Saginaw, Mich.
Greenman, Wilber Eugene, The Texas Co., 902 Jones Bldg., Corpus Christi, Tex.
Gruner, Thayer M., Shell Oil Co., Inc., 2000 Alamo Natl. Bldg., San Antonio, Tex.
Hamblin, Ralph Hugh, Cities Service Oil Co., Box 271, Olney, Ill.
‖Ham, William Otis, Jr., Continental Oil Co., Box 1267, Ponca City, Okla.
Handley, Ernest Jack, British American Oil Producing Co., Philtower Bldg., Tulsa, Okla.
‖Hardin, George C., Jr., Carter Gragg Oil Co., Palestine, Tex.
‖Harding, John William, Jr., Union Oil Co. of California, Los Angeles, Calif.
Hartley, Burton, consulting, Box 1142, Houston, Tex.
Hass, Wilbert Henry, 333 U. S. National Museum, Washington, D. C.
Hatch, Jesse Duff, Jr., Humble Oil & Refining Co., Box 1600, Midland, Tex.
Hawn, Margaret Hayward, W. C. McBride, Inc., Evansville, Ind.
‖Higgs, William Reginald, Carter Oil Co., Natchitoches, La.
‖Hilburn, Sam E., Permian Basin Sample Lab., Midland, Tex.
‖Hoard, John Lucian, Camp No. 4, A. T. B., Fort Pierce, Fla.
Hodge, Edwin T., consulting, 2915 N. W. Luray Terr., Portland, Ore.
‖Horn, George H., U. S. Geological Survey, 425 Denham Bldg., Denver, Colo.
Huffman, Harold LaVergn, consulting, Box 1884, Midland, Tex.
‖Hull, Arthur M., U. S. Engineers, 604 Santa Fe Bldg., Galveston, Tex.
‖Hunter, Frank Rogers, International Minerals & Chemicals Corp., Research Lab., Mulberry, Fla.
‖Iglehart, Charles F., Stanolind Oil & Gas Co., Tulsa, Okla.
Jameson, Paul Marvin, Tide Water Associated Oil Co., Box 731, Tulsa, Okla.
‖Jeffreys, Stanley Rex, Shell Oil Co., Inc., 514 Forum Bldg., Sacramento, Calif.
Johnson, Hamilton McKee, Schlumberger Well Surveying Corp., Box 747, Ardmore, Okla.
Johnson, James F., Sinclair Prairie Oil Co., Fort Worth, Tex.
Johnson, Jane Marie, consulting, Box 225, Midland, Tex.
Johnston, Harry Wilton, Jr., Union Producing Co., Box 2492, Houston, Tex.
Joy, Oliver T., Apt. 2961, Bogota, Colombia, S. A.
Kaveler, Herman Henry, Phillips Petroleum Co., Bartlesville, Okla.
‖King, Helen June, Carter Oil Co., Box 1490, Jackson, Miss.
King, Ralph Hughes, U. S. Geological Survey, Box 829, Carlsbad, N. Mex.
‖Kingston, Benson Madill, Chemical Process Co. Div., Independent Eastern Torpedo Co., Breckenridge, Tex.
Koenig, Joseph B., Texas University Lands, Box 1663, Midland, Tex.
LaBerge, A. Lionel, Imperial Oil Co., Ltd., 302 Examiner Bldg., Calgary, Alta., Canada
‖La Moreaux, Philip Elmer, U. S. Geological Survey, Box 2033, University, Ala.
Landon, Robert E., General Petroleum Co. of California, Box 465, Kemmerer, Wyo.
Layer, Douglas B., McColl-Frontenac Oil Co., Ltd., 707 Lancaster Bldg., Calgary, Alta., Canada
Lehner, Ernest J., Buchillon (Vaud), Switzerland
Lewis, J. Volney, War Production Board, Washington, D. C.
Lewis, Kenneth W., W. C. McBride, Inc., Evansville, Ind.
‖Ley, Ross Henry, 4829 Crestline Rd., Fort Worth, Tex.
‖Lind, Charles McClelland, Humble Oil & Refining Co., Box 1271, Corpus Christi, Tex.
MacAlpin, Archie Justus, U. S. Geological Survey, Box 177, Univ. of New Mexico, Albuquerque, N. Mex.
Mallory, William W., Phillips Petroleum Co., Bartlesville, Okla.
‖Marquez, Gustavo, Box 1672, University Sta., Austin, Tex.
McCann, Franklin T., U. S. Geological Survey, 314 Boston Bldg., Denver, Colo.
McCollum, Aubrey Britton, Deep Rock Oil Corp., Box 1051, Tulsa, Okla.
‖McCosh, Bonnie Enderud, Continental Oil Co., Midland, Tex.
McCracken, Earl, Gulf Oil Corp., 1107 Union Natl. Bank Bldg., Wichita, Kan.
McDowd, Edward L., Shell Oil Co., Inc., 1008 W. Sixth St., Los Angeles, Calif.
‖McKinley, Glenn Ernest, 1728 N. W. Thirty-third, Oklahoma City, Okla.
McLaughlin, Roy P., consulting, 2055 Milan Ave., S. Pasadena, Calif.
‖McMahon, Beverly Edith, Shell Oil Co., Inc., Wichita Falls, Tex.
Means, John B., Jr., Tide Water Associated Oil Co., Box 1548, Jackson, Miss.
Mencher, Ely, Socony-Vacuum Oil Co. of Venezuela, Apt. 246, Caracas, Venezuela, S. A.
Merkt, Ernest E., Jr., Gulf Oil Corp., Box 1290, Fort Worth, Tex.
Milek, William Arthur, Union Oil Co. of California, Box 980, Laramie, Wyo.
Millward, Louis George, Socony-Vacuum Oil Co., Ltd., 62 Sharia Ibrahim Pasha, Cairo, Egypt
Minton, Morris Creswell, 501 Argyle Apartments, Dallas, Tex.
‖Morales, Luis German, Tropical Oil Co., Bogota, Colombia, S. A.
Naffziger, Luther Orlando, Sinclair Prairie Oil Co., Tulsa, Okla.
‖Neel, Henry Howard, Tide Water Associated Oil Co., Ventura, Calif.
Nelson, Donald Oliver, The Texas Petroleum Co., Apt. Postal 877, Bogota, Colombia, S. A.
Noble, Arthur Henry, Anglo-Saxon Petroleum Co., St. Helen's Court, London, E. C. 3, England
Oliver, Donald McCreery, Kerlyn Oil Co., Box 243, Midland, Tex.
O'Rourke, Edward Vincent, Lord Hall, Ohio State University, Columbus, Ohio
Parker, Jack Adriance, Sun Oil Co., Box 1682, Midland, Tex.
Pattison, William Harold, Transwestern Oil Co., 605 Union National Bank Bldg., Wichita, Kan.
Payne, Willard M., The California Co., 1818 Canal Bldg., New Orleans, La.

Pearce, Roy Ward, Socony-Vacuum Oil Co., Box 246, Caracas, Venezuela, S. A.
Peterson, Victor Edwin, Magnolia Petroleum Co., Box 633, Midland, Tex.
Petsch, Bruno Carl, State Geological Survey, Vermillion, S. Dak.
‖Peyser, Gladys Minette, The California Co., 1818 Canal Bldg., New Orleans, La.
Peyton, Garland, Department of Mines, Mining, & Geology, 425 State Capitol, Atlanta, Ga.
Phillips, Lee E., Jr., The Phil-Han Oil Co., 1122 Union Natl. Bank Bldg., Wichita, Kan.
Pierce, Edith Ann, Great Lakes Carbon Corp., Wichita, Kan.
‖Pincomb, Edwin Moats, The Texas Co., Box 415, Chickasha, Okla.
Popenoe, Hubert L., Jr., Shell Oil Co., Inc., Box 999, Bakersfield, Calif.
‖Porter, Hugh, Seismic Explorations, Inc., Box 826, Mansfield, La.
Raggatt, Harold George, Mineral Resources Survey, Department of Supply & Shipping, Canberra, A. T. C., Australia
Randolph, James Richardson, Shell Oil Co., Inc., Box 2099, Houston, Tex.
Rassinier, Edgar A., Phillips Petroleum Co., Bartlesville, Okla.
Rathwell, Harold B., 427 Lupin Way, Ventura, Calif.
Reed, George Wylie, Seismograph Service Corp., 709 Kennedy Bldg., Tulsa, Okla.
‖Reidford, Harry Kenneth, Imperial Oil Co., Ltd., Norman Wells, N. W. T., Canada
Riegle, John, Jr., Southern California Gas Co., Box 3249, Terminal Annex, Los Angeles, Calif.
‖Robeck, Raymond Clifton, U. S. Geological Survey, Box 87, Rifle, Colo.
‖Robertson, Forbes Smith, Standard Oil Co. of New Jersey, Richmond Trust Bldg., Richmond, Va.
Robinson, W. Bernard, Gulf Research & Development Co., Box 2038, Pittsburgh, Pa.
Rodgers, Thompson Deane, Stanolind Oil & Gas Co., Box 689, Jackson, Miss.
Rogers, Carl Pembroke, Jr., U. S. Geological Survey, Box 1658, Billings, Mont.
‖Rohrer, George H., Socony-Vacuum Oil Co., 26 Broadway, New York, N. Y.
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Sampson, Charles Milburn, Freeport Sulphur Co., Box A, Freeport, Tex.
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Scott, James Campbell, Shell Oil Co., Inc., Bank of Toronto Bldg., Calgary, Alta., Canada
‖Seeligson, Arthur A., Jr., Transwestern Oil Co., 1600 Milam Bldg., San Antonio, Tex.
‖Smith, Holly E., Superior Oil Co., Box 510, Midland, Tex.
Spalding, Robert W., Shell Oil Co., Inc., 611 E. Twelfth St., Casper, Wyo.
Sparks, Jackson Bennett, Industrial Gas Corp., Newark, Ohio
Starkey, Caldwell, Stanolind Oil & Gas Co., Garden City, Kan.
‖Stephenson, Robert Charles, Union Oil Co. of California, Box 980, Laramie, Wyo.
‖Stillwell, James Henry, Superior Oil Co., Box 1382, Shreveport, La.
Stoltenberg, Harold Waite, Phillips Petroleum Co., Box 791, Midland, Tex.
Stoneham, Sebron Lloyd, Sun Oil Co., McAllen, Tex.
‖Swanson, Raymond H., Amerada Petroleum Corp., Box 2040, Tulsa, Okla.
‖Sype, William Russell, Stanolind Oil & Gas Co., Tulsa, Okla.
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Thomas, William Henry, Shell Oil Co., Inc., Box 691, Ventura, Calif.
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Trostel, Everett G., DeGolyer & MacNaughton, 1000 Continental Bldg., Dallas, Tex.
‖Trout, Kye, Jr., Gulf Oil Corp., Box 4232, Odessa, Tex.
‖Underwood, Lloyd Bradish, U. S. Geological Survey, Washington, D. C.
‖Van Norden, Peter John, Socony-Vacuum Oil Co., 26 Broadway, New York, N. Y.
‖van Rossum, Otto, Mexican Gulf Oil Co., Box 106, Tampico, Tamps., Mexico
‖Van Siclen, De Witt Clinton, 264 Park Lane, Douglaston, Long Island, N. Y.
Vonderschmitt, Louis, Geol. Pal. Institut, Bernoullianum, Basel, Switzerland
‖Wagner, C. Philip, Superior Oil Co., 506 First National Bank Bldg., Denver, Colo.
Waidhofer, Joe John, Barnsdall Oil Co., Box 873, Midland, Tex.
Walsworth, Kenneth G., Geological Survey Div., Department of Conservation, Lansing, Mich.
‖Ware, William Edmond, The California Co., 1818 Canal Bldg., New Orleans, La.
Watson, John Gaul, Shell Oil Co., Inc., Box 1347, Shreveport, La.
Weaver, Thomas James, Michigan Consolidated Gas Co., 47 Division Ave., N., Grand Rapids, Mich.
‖Webb, Byron K., General Petroleum Corp., Los Angeles, Calif.
Whaley, Harry Max, Tide Water Associated Oil Co., Box 811, Ventura, Calif.
White, George W., Orton Hall, Ohio State University, Columbus, Ohio
White, Gordon Ashbridge, Apt. B-359, 2710 Thirtieth St., S.E., Washington, D. C.
Wiedenmayer, Carl, Standard Oil Co. of New Jersey, 30 Rockefeller Plaza, New York, N. Y.
Wilkins, Edwin Lewis, Danciger Oil & Refining Co., Baton Rouge, La.
‖Williams, William Paul, Stanolind Oil & Gas Co., Amarillo Bldg., Amarillo, Tex.
Wilpolt, Ralph Henry, U. S. Geological Survey, Box 177, Univ. of New Mexico, Albuquerque, N. Mex.
‖Wilson, Wallace Woodrow, Ryder Scott Co., Box 108, Bradford, Pa.
‖Womack, Robert, Jr., 203 S. Waverly Dr., Dallas, Tex.
‖Woods, Peter Gerald, Jr., Seaboard Oil Co. of Delaware, Bakersfield, Calif.
Woodward, Jack Spurgeon, Magnolia Petroleum Co., Box 900, Dallas, Tex.
Woollard, George Prior, Woods Hole Oceanographic Inst., Woods Hole, Mass.
‖Young, W. Ford, Colombian Gulf Oil Co., Apt. Nac. 1339, Bogota, Colombia, S. A.
‖Yust, Morton R., The Texas Co., Box 1801, Wichita, Kan.

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MEMORIAL

DONALD FROST NEWELL
(1911–1944)

Lieutenant Colonel Donald Frost Newell, Field Artillery, was reported by the War Department as having died, December 7, 1944, in the Army General Hospital, Brisbane, Australia. Particulars as to the cause of Colonel Newell's death have not yet been reported to the immediate family. However, the last letters from him, written from a station hospital in New Guinea, tell of an accident by which a bullet from an army pistol entered his left knee. X-rays indicated the bone to be undamaged and apparently an early and complete recovery was predicted. After six weeks' hospitalization in New Guinea, Colonel Newell's recuperation was not as satisfactory as anticipated and, with the thought that a change in climate might be of benefit, he was given leave to go to Australia. A wire from the War Department in late November, 1944, reported him seriously ill in the Army General Hospital at Brisbane—this being followed a week later by the second message reporting his death on December 7, as a war casualty.

Colonel Newell was born at Franklin, Franklin County, Nebraska, on November 24, 1911, the son of Reverend Arthur Frost and Alice Bross Newell. His parents later moved to Garner, Iowa, and subsequently to Blair, Nebraska, where Donald received his early education, having been graduated from high school in 1929. While a student in Blair High School he was a member of the high-school orchestra and took a prominent part in other school activities. His loyalty and courage were responsible for establishing a reputation as one of the leading players on the football team.

Don chose geology as his profession early in life and selected the University of Oklahoma as the most appropriate school to secure his formal education. In the fall of 1929 he enrolled as student in the School of Geology. Under the guidance of Professors C. E. Decker, V. E. Monnett, R. W. Harris, G. E. Anderson, and others, he soon began to develop the leadership and ability with which he gained outstanding achievements in later life.

His college work was broken for a period of two years, during which he supervised a C.C.C. camp in the Black Hills under the direction of the War Department. After his return to the University of Oklahoma he exhibited a renewed interest in military matters and was promoted to ranking Major in the R.O.T.C. artillery battalion and upon graduation received a Lieutenant's commission as a U. S. Army Reserve Officer. In the spring of 1936 Don received a B.S. degree in geology with first honors. In addition to his devotion to the studies of geology and military science, he earned a major part of his expenses while in college.

He joined the geological staff of Phillips Petroleum Company immediately following his graduation and began work at El Dorado, Arkansas. In January, 1937, he was given a geological assignment in Lexington, Kentucky, which terminated in June of that year. Don was then transferred to Corpus Christi, Texas, where he remained until entering active military service. His enthusiasm, loyalty, and aptitude for solving many geological problems on the Gulf Coast were rewarded by increased responsibilities. In June, 1939, he was promoted to the position of assistant district geologist of the Gulf Coast area. In this position he did outstanding work in directing Phillips Petroleum Company's development and exploration programs.

With the anticipated war in Europe in 1940 and 1941, Don was called in April, 1941, as a First Lieutenant, for the periodical refresher course required of reserve officers. He was stationed at Fort Bliss, El Paso, Texas, at the time of the Pearl Harbor assault on December 7, 1941, after which he was in active service for the duration.

In February, 1942, he was made a Captain in the Field Artillery and during maneuvers in Louisiana in the summer of that year he was liaison officer to brigade headquarters and

DONALD FROST NEWELL

was made a member of the general staff as G-3, in charge of training artillery troops. After completing a three months' course in artillery technique at Fort Sill, Oklahoma, Don was promoted to the rank of Major in November, 1942, and became commanding officer of a field-artillery battalion.

Don's artillery unit and the First Cavalry Division (unmounted), to which it was attached at Fort Bliss, were ordered to Australia in the spring of 1943. After eight months' of maneuvers and instruction in methods of jungle warfare, the two units were ordered by General MacArthur to make landings on, and take, the Admiralty Islands, north of New Guinea. This they did during February and March, 1944, the battles being of equal severity and costliness to those of Tarawa and Guadalcanal.

During sixteen days and nights of jungle fighting on Manus Island, of the Admiralty Group, Don was continuously on the front line and under fire. In this operation Lieutenant General Verne D. Mudge, his commanding officer, cabled headquarters requesting Don be given a combat promotion from Major to Lieutenant Colonel, which was immediately granted. The dispatch with which Don carried out his assignments in this action, for which he was later awarded the Bronze Star medal, is described by a certificate dated, June, 1944, and signed by Brigadier General Verne D. Mudge and Captain Peter H. Comnas as follows.

> The work of this officer was outstanding and was a major individual contribution to the success of the operation. Not only was Lieutenant Colonel Newell called upon to control all artillery fires, but he also was given the task of coordinating air and naval supporting fires. He alone was responsible for receiving all calls for reinforcing fires, whether ground, air or naval.
>
> Lieutenant Colonel Newell accepted this grave responsibility and performed his mission with superior judgment, calmness, and dispatch. He was on duty for long periods, and under the most adverse conditions of weather and terrain.

The Bronze Star medal, for those whose achievements have been so heroic and meritorious during combat against the enemy of the United States as to distinguish them above their comrades, was presented to Don by direction of the President on September 17, 1944.

During the summer of 1944 Don was busy as a member of the general staff in planning the invasion of the Philippines, scheduled for early October. His accident occurred, September 29, 1944, and during his hospitalization his unit was ordered to Leyte, Philippine Islands.

Don became a member of A.A.P.G. in 1938 and always maintained an active interest in the Association. He was an active member of many organizations, including Sigma Xi, Sigma Gamma Epsilon, Pick and Hammer Club, and Scabbard and Blade.

Colonel Newell is survived by his wife, Frances, to whom he was married on October 11, 1931; a son, Lee, age 10; and a daughter, Nancy, age 9, all now living at Blair, Nebraska. He is also survived by his parents, Reverend and Mrs. A. F. Newell of 2723 Webster Avenue, Kansas City, Kansas; by a brother, Perry, of Chicago, but now a radar man on a navy transport in the Pacific area; and by two sisters, Mrs. Martha N. Sprecher of 1815 Cleveland Avenue, Kansas City, Kansas, and Mrs. Lydia N. Marvin of 3129 41st Avenue, S., Minneapolis, Minnesota.

To those who knew Colonel Newell well, his military record reflects the honorable character we have always associated with him. He was a modest man of high moral standards, being outstandingly clean in mind, heart, and body. His contributions of good will, fair play, honesty, and sincerity of purpose are lasting monuments to all who knew him.

D. E. LOUNSBERY
N. P. ISENBERGER

BARTLESVILLE, OKLAHOMA
July 27, 1945.

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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

ROY L. BECKELHYMER has resigned from the Union Producing Company to open his own office as consulting geologist in the Mellie Esperson Building, Houston, Texas.

J. F. GALLIE has resigned his position as senior geologist of the Arkansas Oil and Gas Division at El Dorado, Arkansas, to accept a position as geologist with the Cabot Carbon Company of Pampa, Texas.

OSCAR HATCHER, geologist with Helmerich and Payne, Tulsa, Oklahoma, has a brief article in the *Oil Weekly* of August 20, entitled "Foreign Oil Can Be U. S. Asset." He suggests the use of natural underground reservoirs in depleted fields for storing surplus oil.

1st Lieutenant ROBERT W. EVERETT, JR., is now detachment commander of an AACS radio station in Brazil and can be reached at the following address: Det 157th AACS SQ., APO 619, c/o P.M., Miami, Florida.

L. F. MCCOLLUM, of New York, and O. C. WHEELER, of Toronto, are new members of the board of directors of the International Petroleum Company, Ltd.

MILAN D. MARAVICH has been discharged from Army service and is working for the Stanolind Oil and Gas Company, stationed at Wichita, Kansas. For a time Maravich served with the Petroleum Administration for War in the Tulsa, Oklahoma, office.

DONALD L. NORLING, formerly district geologist in Oklahoma for the Devonian Oil Company, has been transferred to Fort Worth, Texas, where the company recently established the main office of the land and geological departments.

Captain KIRK S. WHITE returned last February from duty as combat intelligence officer in the Air Corps, and has resumed his consulting practice at Tulsa.

H. K. ARMSTRONG, formerly with the Richfield Oil Corporation, is a consulting geologist, 430 Van Nuys Building, Los Angeles, California.

Major R. B. DOWNING has been relieved from active duty in the Air Corps. He is with the Lane-Wells Company, Oklahoma City.

Lieutenant JOHN R. ELLIS, JR., of Helena, Montana, is at the Photo. Int. Center, Anacostia, D. C.

Major RICHARD K. PUNCHES, of the Phillips Petroleum Company is in the Corps of Engineers. His home address is 369 Jackson Street, Hempstead, New York.

Lieutenant JOHN P. POTSCH, of Cicero, Illinois, is in the Navy.

Lieutenant HOMER O. WOODBURY, of Boulder, Colorado, may be addressed: VN-8, U. S. Naval Academy, Annapolis, Maryland.

Lieutenant WILBURN H. AKERS, of Oklahoma City, Oklahoma, is now military governor of Lenz, Austria. He has been overseas more than 3 years, and has been in battle service in Africa, Italy, and Germany.

Ensign WICHITA F. SHELDON, of the Shell Oil Company, Inc., is in the Navy, at the Hydrographic Office, Washington 25, D. C.

EDWARD RICHARD RIES, of Freeman, South Dakota, is in the Infantry, Division Headquarters.

Captain HARLAN WILLARD NEWELL, 2692 Landon Road, Cleveland, Ohio, is in military government.

Ensign STEWART H. FOLK, of the Illinois Geological Survey, is overseas. His home address is 401 North Elm, Little Rock, Arkansas.

Lieutenant BEVERLY BRADISH, of the Carter Oil Company, is in the Navy.

B. E. THOMPSON has been appointed division superintendent in the production department of the Gulf Oil Corporation, at Fort Worth, Texas. Thompson has been on the geological staff of the Gulf for 26 years. GORDON H. FISHER becomes chief production engineer.

Lieutenant MARK L. ORR, of Idalou, Texas, was reported missing in action since April 13, 1945. He was in naval aviation.

Captain MAXWELL ROLAND SARTAIN, of Oklahoma City, Oklahoma, is in the Army Air Force at Orlando, Florida.

Lieutenant NORMAN CUTLER SMITH, of Somerville, New Jersey, may be addressed: P.I.C., Navy Yard, Washington 25, D. C.

Lieutenant TENNANT BROOKS, formerly with the Union Oil Company of California, Bakersfield, California, is in the Navy Air Corps.

GEORGE I. MCFERRON recently resigned from the Whiggins and McFerron Oil Company and is now working for the Sohio Petroleum Company as district geologist at Houston, Texas.

GUY M. RATLIFF has resigned his position as geologist for Al Buchanan of San Antonio, and has taken a position with the Petty Geophysical Engineering Company, San Antonio, Texas.

JAMES NORMAN PAYNE, recently with the Stanolind Oil and Gas Company at Wichita, Kansas, is with the Bureau of Research, Department of Geology, University of Arkansas, Fayetteville, Arkansas.

FANNY C. EDSON, consulting geologist, may be addressed at 703 Petroleum Building, Wichita, Kansas.

CLARENCE J. PETERSON is chief geologist of the Texoma Natural Gas Company, Amarillo, Texas.

R. M. STAINFORTH has left the geological laboratory of Trinidad Leaseholds, Ltd., Pointe-a-Pierre, Trinidad, to engage in micropaleontological work in Ecuador for the International Ecuadorean Petroleum Company, Box 803, Quayaquil, Ecuador.

SIDNEY SCHAFER, formerly geophysicist for the Pan American Production Company, has opened an office as a consulting geophysicist, and may be addressed at 1248 Mellie Esperson Building, Houston 2, Texas.

An unfortunate typographical error occurred in the advertisement of the Mayes-Bevan Company on page iv of the July *Bulletin*, appearing to change the name of the company. Mayes-Bevan Company specializes in gravity-meter surveys. Company offices

are in the Kennedy Building, Tulsa, Oklahoma. The members of the firm are TOM D. MAYES and THOMAS J. BEVAN.

GLENN C. FERGUSON, who has been division micropalentologist with the Union Oil Company of California since 1933, has opened an independent laboratory in his capacity as petroleum geologist and paleontologist. His address is Room 1, Professional Building, 1829 H St., Bakersfield, California.

Lieutenant JAMES PHILIP BOYLE, JR., of Oklahoma City, Oklahoma, is in Amphibious Group Six, U. S. Pacific Fleet.

Lieutenant FRANK REEDY may be addressed: Navy 3011, Div. 3, c/o F.P.O., San Francisco, California.

RAYMOND A. VAN EATON, of Houston, Texas, with Mills Bennett, 3402 Gulf Building, is on terminal leave from military service.

D. A. PROBST is with the Mene Grande Oil Company, Barcelona, Venezuela. He was recently with the Gulf Oil Corporation at Pittsburgh, Pennsylvania.

T. PRESTON WARE, JR., is geologist for Baldridge & King, McAllen, Texas.

WILLIAM ALBERT MCMORRIS, of the Carter Oil Company, Tulsa, Oklahoma, is in the Air Corps.

JOE CANNON, who has been with the Petroleum Administration for War at Chicago, Illinois, has returned to 808 McBurnett Building, San Angelo, Texas.

ROBERT L. JOHNSTON has resigned from the Stanolind Oil and Gas Company at Wichita, Kansas, and is now with the Superior Oil Company of California in Denver, Colorado.

Captain JAMES HELIS is in the Ordnance Department. He may be addressed: Ord. Sect. AFHQ, APO 512, c/o P.M., New York, N. Y.

Captain ROBERT S. HACKETT, of the General Petroleum Corporation of California, is with the Marine Bomber Sq. 433, c/o Fleet Postmaster, San Francisco, California.

Captain MARLOW D. MELVIN, of Columbus, Ohio, is in the Infantry: AT Co., 379th Inf., 95th Div., Camp Shelby, Mississippi.

Lieutenant Colonel F. B. CONSELMAN, of Wichita, Kansas, is in the Air Corps.

Corporal NORMAN EWBANK is at Camp Callan, California: 595 JASCO, Sec. 8.

MARION R. DE ESCALLON may be addressed: Taca de Colombia, Apartado Nacional 2727, Bogota, Colombia.

B. O. WINKLER is with the Standard-Vacuum Oil Company, 26 Broadway, New York, New York.

FRANK A. SCHULTZ, formerly with the American Liberty Oil Company, Dallas, is now with the Southern Union Gas Company, Burt Building, Dallas, Texas.

LLOYD B. UNDERWOOD is with the United States Geological Survey, Washington 25, D. C.

JOHN R. FANSHAWE, of the General Petroleum Corporation of California, has been transferred from Billings, Montana, to the division office at Casper, Wyoming.

The Phillips Venezuelan Oil Company is operating in eastern Venezuela. Association members who are key men in the Phillips foreign exploration program are: D. R. KNOWLTON, Bartlesville, vice-president; N. P. ISENBERGER, of Bartlesville, director of exploration for the foreign department; F. W. FLOYD, Caracas, general manager; C. P. BONG, Caracas, chief geologist; STEWART BARCLAY, Caracas, chief geophysicist.

FRED P. SHAYES, district geologist for the Union Producing Company, at Beeville, Texas, has been promoted to the position of district manager. Shayes has been at Beeville 20 years.

D. W. ST. CLAIR, after nearly 10 years with the Shell Oil Company in the Mid-Continent, Eastern, and Gulf Coast areas as surface, subsurface, and research geologist, has resigned to become connected with DeGolyer and MacNaughton, of Dallas. His address will be Box 51, Midland, Texas.

CLAUDE W. HORTON, formerly with the Underwater Sound Laboratory, Harvard University, is now senior geophysicist with The Texas Company. He will be stationed in Bogota, Colombia.

H. H. POWER, professor of petroleum engineering at the University of Texas, is in Caracas, Venezuela as a special consultant to the Mene Grande Oil Company.

RAYMOND D. SLOAN, head of the Carter Oil Company's scouting and statistical division at Tulsa, has been transferred to Billings, Montana, as division geologist, succeeding D. L. BLACKSTONE, who has returned to the University of Missouri as associate professor of geology.

HAROLD B. FOXHALL has resigned from the U. S. Geological Survey to become director of the division of geology of the Arkansas Resources and Development Commission, Little Rock, Arkansas.

Six workers in different phases of earth science in the High Plains and related and adjacent regions attended a field conference, in August, on the geomorphology and late Cenozoic geology of the Llano Estacado at the invitation of W. ARMSTRONG PRICE and MAXIM K. ELIAS. Objectives were the origin and stratigraphy of the Ogallala formation and the validity of its "cap-rock" limestone as a structural key bed, the geomorphology of the plateau, and the nature of the Quaternary deposits involved in its history. Those completing the main conference trip were: MAXIM K. ELIAS, paleontologist, Nebraska Geological Survey; JOHN C. FRYE, assistant State geologist, Kansas; C. RICHARD MURRAY and UTLEY N. BENGE, geologists, Division of Ground Water, United States Geological Survey, Albuquerque, New Mexico; EDWARD H. TEMPLIN, soil scientist, assistant soils inspector, Bureau of Plant Industry, Department of Agriculture, College Station, Texas; W. ARMSTRONG PRICE, geologist, Corpus Christi, Texas, leader of the conference. A side trip to the Carlsbad region was led by RONALD K. DEFORD, chief geologist, Argo Oil Corporation, Midland, Texas, accompanied by W. A. WALDSCHMIDT, geologist, of the same company. Definite results in correlation of the Ogallala between the northern and southern parts of the High Plains are believed to have been obtained and important regional contrasts in geomorphology noted. The lithology of the Ogallala "algal" limestone of Kansas and typical algal bioherms were identified on the Llano Estacado. An approach to an understanding of the obscure origin of "caliche" cap rocks of the semi-arid regions seems to have been accomplished.

NOYES B. LIVINGSTON has resigned his position as chief geologist for Y.P.F. Bolivianos, after the completion of his 2-year contract. His home is in Fort Worth, Texas.

HAROLD W. HAIGHT has left the Standard Oil Company of Egypt, at Cairo, to become production manager for the Creole Petroleum Corporation at Caracas, Venezuela.

R. G. SOHLBERG has been transferred from the Richmond Petroleum Company of Colombia, at Bogota, to the Richmond Exploration Company of Venezuela, at Maracaibo.

Sergeant LAURENCE F. DAKE, of Rolla, Missouri, is in the Air Corps.

Sergeant FRED S. LILLIBRIDGE, of Wichita, Kansas, has the following military address: A Co., 654th Engr. Topo. Bn., A.P.O. 403, c/o Postmaster, New York, N.Y.

Captain ROBERT J. CHAMBERS, of the Phillips Petroleum Company, Houston, Texas, may be addressed: Hq. 3d Bn., 119th Infantry, A.P.O. 3c, New York, N. Y.

R. D. MCCLUER, of Midland, Texas, is with the Phillips Venezuelan Petroleum Company, Caracas, Venezuela.

L. W. LEROY has returned to rejoin the geological department of the Colorado School of Mines, Golden, Colorado, following the termination of the South Mediterranean Oilfields, Ltd. (subsidiary of the Standard Oil Company of California), in Egypt.

It is reported from Russia that seismic prospecting during the period of the war has increased the belief that oil deposits beneath the Caspian Sea are larger than those beneath the surface of the Apsheron Peninsula. More than a third of the oil produced in the Baku area comes from wells completed at points under the sea.

JOHN M. WARE has resigned as assistant manager of exploration for the Deep Rock Oil Corporation after 19 years with that company. He has opened an office as geological consultant in Tulsa, Oklahoma.

WILSON B. EMERY, vice-president and manager of production of the Ohio Oil Company, Findlay, Ohio, has been elected a member of the board of directors to fill the vacancy caused by the retirement of C. L. Fleming.

NORVAL E. BAKER, chief geologist for the Iraq Petroleum Company, Ltd., is returning from New York to London, after having made arrangements for extensive geophysical surveys in the Middle East.

OREN C. BAPTIST, recently with the Socony-Vacuum Oil Company de Colombia at Bogota, Colombia, is engaged in subsurface geology and petroleum engineering for the General Petroleum Corporation at Casper, Wyoming.

Lieutenant LUTHER DAVID HAWLEY, of The Texas Company, is in the Naval Reserve. His home address is Box 147, Saunderstown, Rhode Island.

CAROLINE E. HEMINWAY, associate professor of geology at Smith College, Northampton, Massachusetts, has returned after a leave of absence of 2 years during which time she was senior paleontologist for the Shell Oil Company, Inc., at Houston, Texas.

LUIS CAMMINATI-CORTES has graduated from the Petroleum Engineering School at the University of Texas, Austin, and has joined the petroleum engineering staff of the International Petroleum Company at Negritos, Peru.

R. G. MURPHY, of the Union Producing Company, has been transferred from Shreveport, Louisiana, to Tyler Texas, where he is district geologist in the new East Texas district office.

CHESTER REAMS THOMAS is working for the United States Geological Survey at Denver, Colorado.

PARK J. JONES, consulting petroleum engineer of Houston, formerly with The Texas Company, is the author of a series of articles on "The Optimum Rate of Production of Oil, Condensate, and Natural Gas," in the *Oil and Gas Journal*.

EUGENE HOLMAN, president of the Standard Oil Company (New Jersey), has announced plans for two new oil-research centers, one at Linden, New Jersey, and one at Baton Rouge, Louisiana, to be completed in 1946 or 1947. The new laboratories are to be used for developing new and improved products from oil and for extending sources of supply, including production of oil from natural gas, gasification of coal, production of coal, production of oil from coal, and other research.

S. C. PALMERSTON is with the United Geophysical Company, Inc., Apartado Aereo 465, Barranquilla, Colombia.

Lieutenant RICHARD F. MILLER, of Aurora, Colorado, is in the Army Air Corps, Box 2196, O.M.S., Lowry Field, Colorado.

LLOYD W. STEPHENSON, principal geologist of the United States Geological Survey, has moved his residence from Washington, D. C., to 4620 Rosedale Avenue, Bethesda, Maryland.

Captain ROBERT SINCLAIR DIETZ, of Urbana, Illinois, is in the Air Corps Reserve, Hendricks Field, Florida.

Lieutenant WILBUR FRANK ROGERS, of Seward, Nebraska, may be addressed: U.S.S. Karnes APA 175, F.P.O., San Francisco, California.

EDMOND G. OTTON, III, is in the Chemical Warfare Service, Edgewood Arsenal, Maryland. His home is 404 South Cuyler Avenue, Oak Park, Illinois.

Captain JOSEPH G. HATHEWAY is with the 72d AAF Base Unit, 23d Weather Region, Peterson Field, Colorado Springs, Colorado.

Major LYNN D. ERVIN, of the Stanolind Oil and Gas Company, is in the U. S. Marine Corps, MTC, Camp Pendleton, California.

WILLIAM E. HUMPHREY, formerly with the Texas Petroleum Company, Caracas, Venezuela, may be addressed: Ultramar S.A.P.A., Leandro N. Alem 619, Buenos Aires, Argentina.

FRANK W. MICHAUX, oil operator, 1609 Commerce Building, Houston, Texas, has returned to inactive military duty.

KEITH M. HUSSEY has returned from Army Air Service to his position at the University of Houston.

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Secretary-Treasurer - - - Edward A. Huffman
J. M. Huber Corporation, 407 First National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

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The California Company, 1818 Canal Bldg.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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Sohio Petroleum Corporation, Atlas Building

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Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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Business Manager - - - Harry J. Hardenberg
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

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Box 2571, W. Jackson Sta.

Secretary-Treasurer - - - - - J. B. Wheeler
Stanolind Oil and Gas Company

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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Stanolind Oil and Gas Company
Box 1633

Secretary-Treasurer - - - - - Carl A. Moore
Carter Oil Company
1300 Apco Tower

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second Thursday, at 12:00 noon. Skirvin Hotel.

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Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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U. S. Geological Survey, Box 311

Editor - - - - - - - - Charles J. Deegan
Oil and Gas Journal, Box 1260

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

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Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

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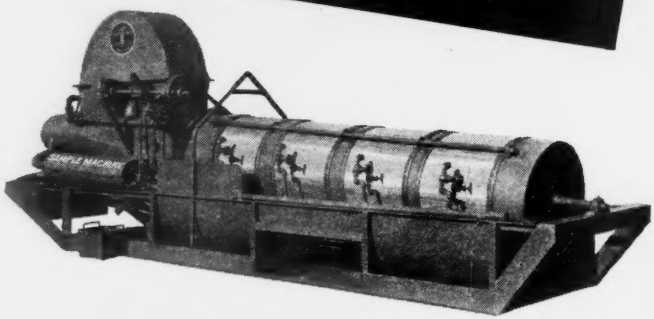

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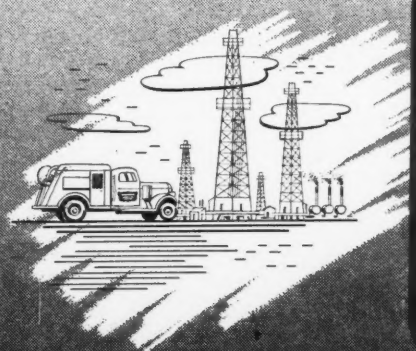

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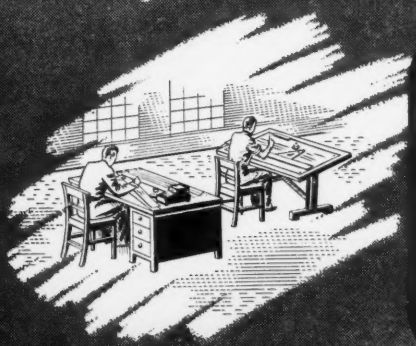

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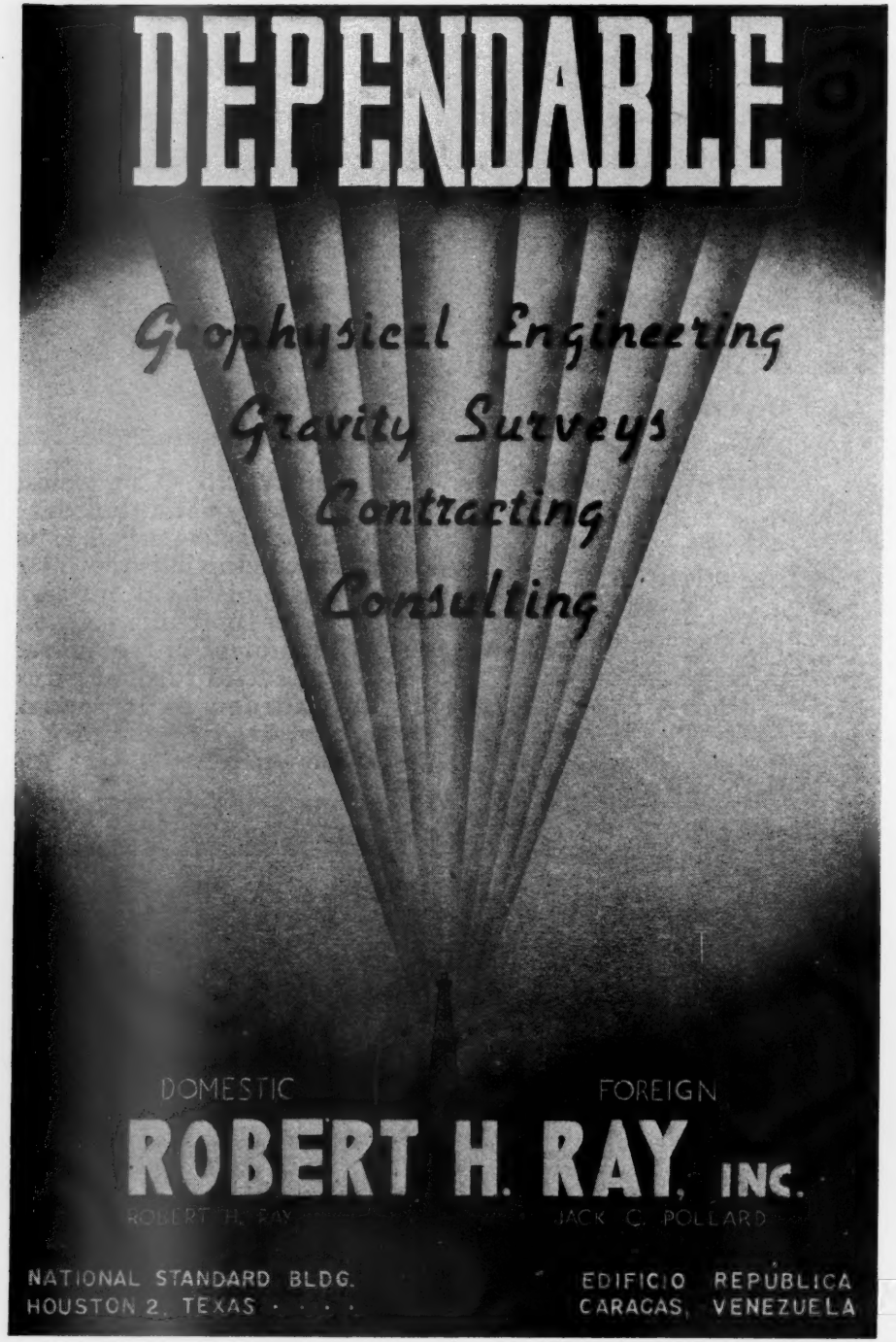
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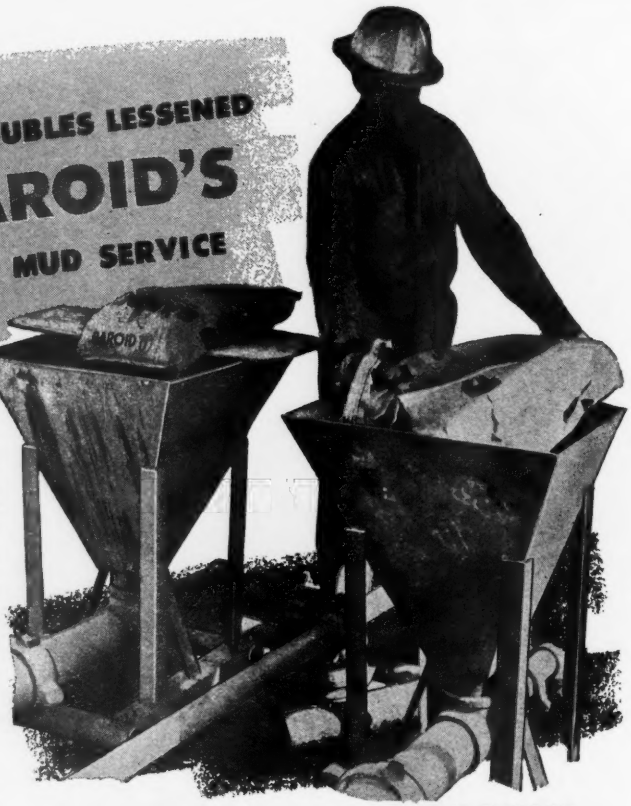

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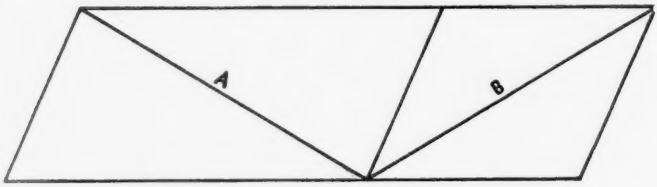

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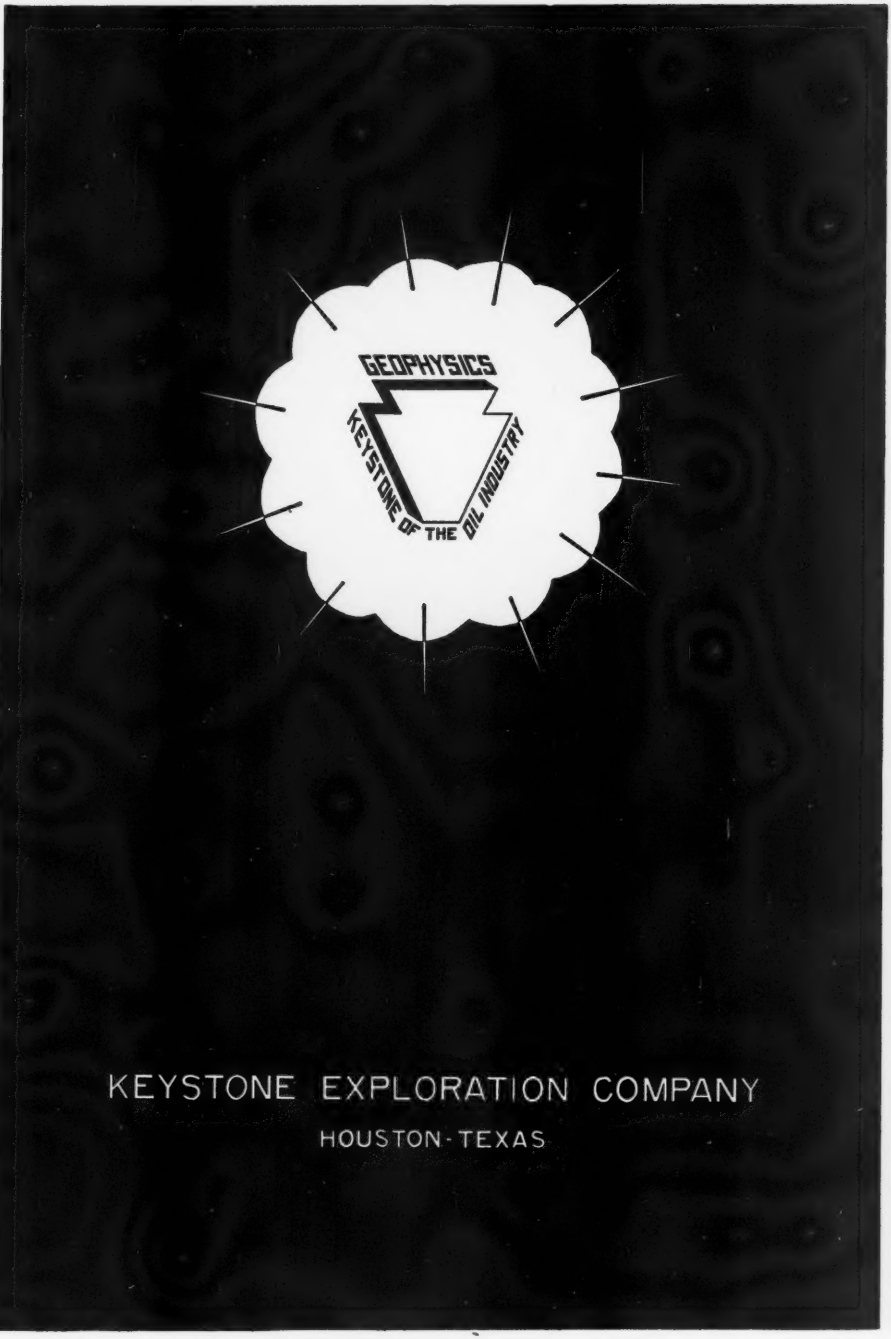
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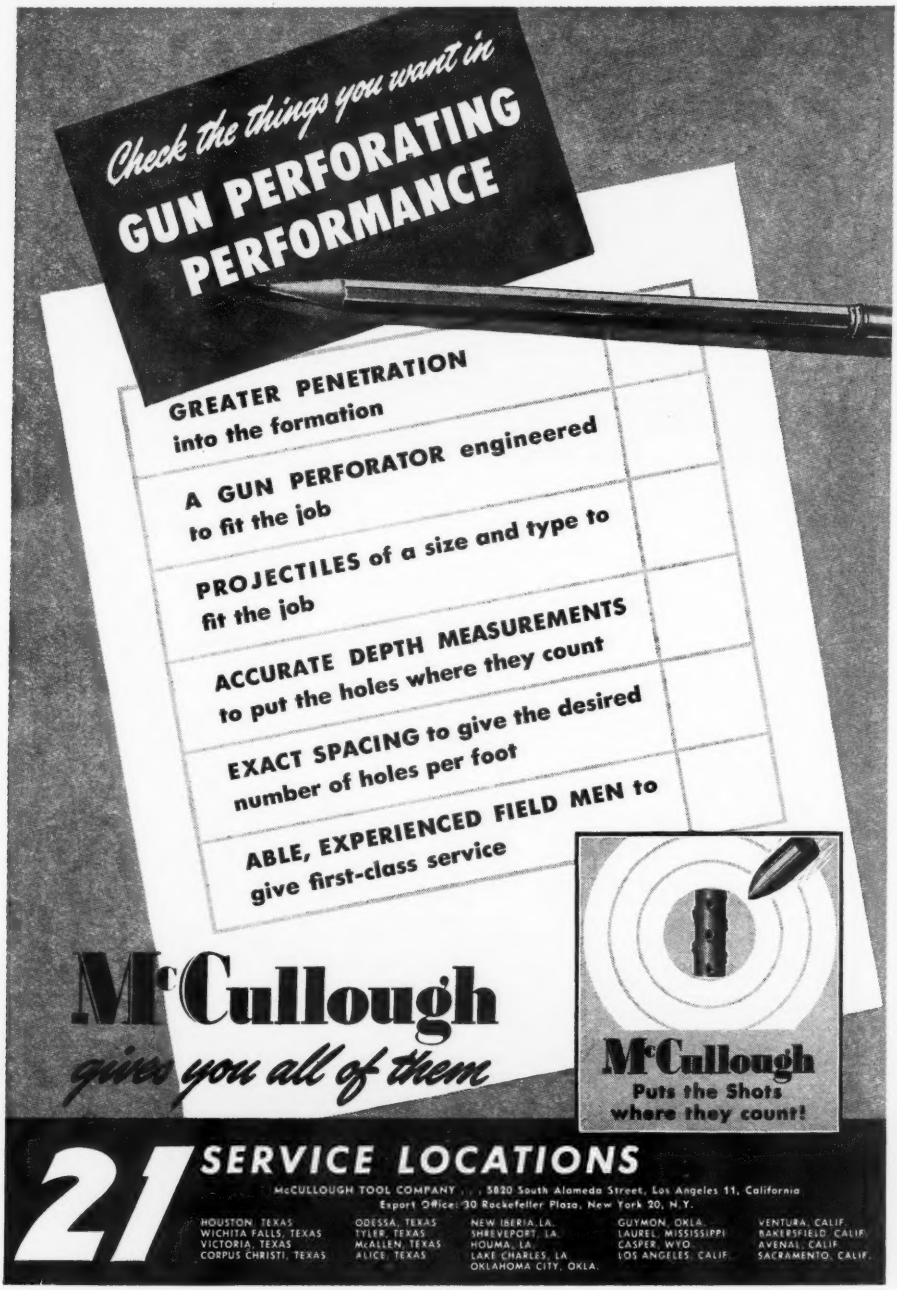
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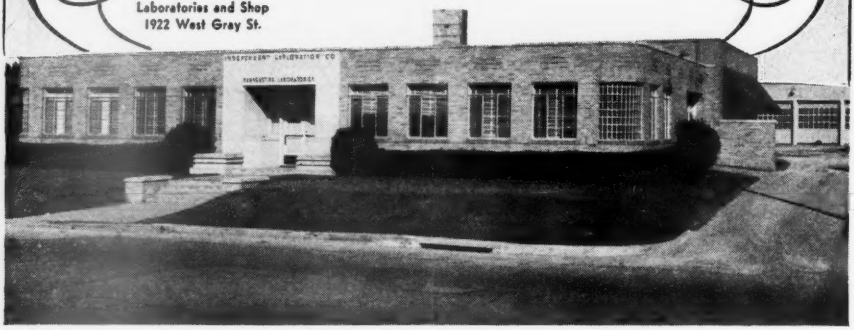

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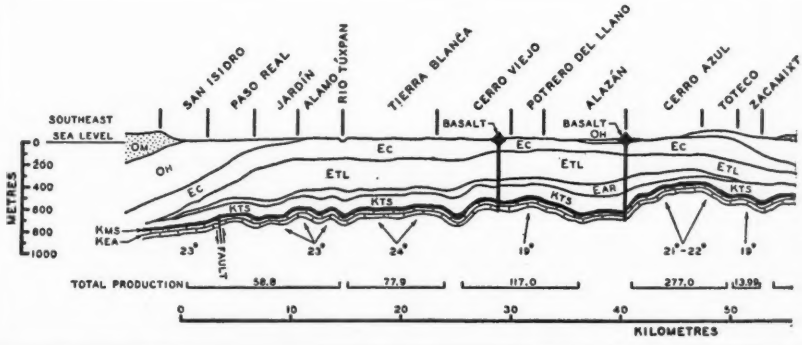

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